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FINAL REPORT
STUDY OF HOUSEKEEPING CONCEPTS FOR MANNED SPACE SYSTEMS

Prepared for
NATIONAL AERONAUTICS and SPACE ADMINISTRATION
Manned Spacecraft Center
Houston Texas 77058

Contract NAS 9-10662
DRL Line Item No. 2

Prepared by
Manned Space Systems
Advanced Programs
FAIRCHILD HILLER
REPUBLIC AVIATION DIVISION
FARMINGDALE, NEW YORK 11735

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ABSTRACT

A Data Book was generated on the waste control aspect of housekeeping for future manned orbital missions. The data is intended for use by the mission planner, to permit overall assessment of the waste control problem, crew assignments and logistics planning; the spacecraft conceptual designer, for selection of equipment for handling, processing and disposal; and the equipment designer, by providing conceptual designs of procedures and equipment.

The information contained in the Data Book is in parametric from applicable to crew sizes up to 100 men, a spacecraft life of up to 10 years, and a wide range of mission tasks and experiments. The subjects covered are:

- Identification of waste products, their source, rates of generation and interfacing information for handling and processing.
- Utilization processes to reclaim or convert waste products to consumables/ expendables in lieu of logistical resupply
- Pretreatment processes for disposal for deactivation or sterilization of organic or potentially pathegenic wastes and the compaction and packaging of deactivates wastes.
- Waste disposal concepts for separating waste products from the spacecraft
- Waste control and housekeeping data for crew procedures and assignment planning, manual and automated equipment for waste collection, pickup, transfer and sorting,and information on crew interfacing with processing and disposal equipment
- Search/Report Computer Program for the storage of the large volume of data included in the Data Book and permitting the performance of automated searches.

This report summarizes the content of the Data Book and potential usage of the data and presents recommendations for future work in the problem areas of waste control.

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ILLUSTRATIONS

TABLES

1.0 INTRODUCTION

A study of the waste control aspects of housekeeping for future manned orbital spacecrafts was undertaken under Contract No. NAS 9-10662 for the Manned Spacecraft Center, Houston, Texas. The purpose of the study was to produce a Data Book containing a definition of the potential waste products and data on their attributes and rate of generation as well as procedural and hardware concepts for waste control.

Housekeeping for manned space systems include the routines and equipments to collect, transfer, pretreat, utilize, and dispose of the wastes produced by the crew members and the systems and laboratories required to support life, operate the space system, and perform its missions and experiments. The housekeeping routines and equipments interface with all of the crew tasks, including experiment and mission operations, medical research and operations, system operations, dining, recreation, sleep, and personnel hygiene. The housekeeping routines, in the sense that they require crew time, reduce the crew time available for performance of the spacecraft's missions and experiments. The routines and equipments interface with the habitability items and systems including architectural, environment, food systems, waste management systems, personal hygiene, clothing, laundering and sleep equipment, off-duty equipment, and motion and handling aids. They also interface with essentially all of the spacecraft systems, laboratories, core modules, attached and free flying modules, cargo/pantry/waste modules, and waste processing and disposal modules. They significantly affect both the shuttle down-cargo and up-cargo; a major down-cargo will be wastes and the requirements for up-cargo will depend largely on the waste utilization equipments on-board the spacecraft.

The Data Book provides information that can be utilized for the initial identification of these interfaces for future manned spacecraft. The Data Book also can be used for the performance of crew task trade-off studies, equipment trade-off studies, and crew task-equipment trade-off studies; for the performance of crew-task and equipment concept selection, preliminary design and requirement studies, and for the determination of appropriate mock-up fabrication and evaluation programs, as well as equipment development programs.

The following is a description of the three basic sections to this report.

- Section 2.0 - Conduct of Study

  This section contains the study approach, including the mission model, and a detailed discussion of the study methodology. Figure 2-1 and the discussion presented is, in addition to being the method by which the program was pursued, a basic rationale for the study of the waste control problems for specific spacecraft and the selection of waste control procedures and equipment.

- Section 3.0 - Results of Study

  This section contains a discussion and/or condensation of the information presented in the Data Book. It includes a discussion on the use of the waste generation data of Volume II of the Data Book, a summary of the information on waste utilization processing, concepts for pretreatment for disposal, candidate disposal techniques, and data on the crew interface with waste control procedures and equipment. In addition, a discussion is presented on a Search/Report Computer Program developed to handle to large volume of data generated during the study.

- Section 4.0 - Recommendations for Future Work

  Included are recommendations for the updating, expansion and application of the data generated during this study; recommendations in areas related to or interfacing with waste control, and recommendations concerning waste control hardware definition or development.

2.0 CONDUCT OF STUDY

2.1 STUDY APPROACH

The objectives of the study were to identify the waste products to be generated onboard future orbital spacecrafts, their potential for onboard utilization, pretreatment requirements for storage and/or disposal, disposal concepts, and the attendent crew housekeeping requirements for waste control.

2.1.1 Mission Model

The intent of the study was to cover typical post-Apollo earth orbital missions, ranging from the smaller 6 to 12 men Space Stations to large Space Bases with crew sizes up to 100 men. As general guide lines, the following parameters were established:

• Orbit altitude	300 nautical miles (maximum)
• Orbit inclination	55 degrees
• Mission duration	Up to 10 years
• Resupply intervals	30 days (maximum)
• Crew	100 (maximum) all male crew

The study data generated was not particularly sensitive to the orbit altitude or inclination. To cover a wide range of mission durations, resupply intervals and crew size, the data generated was in parametric form and not identified to a specific mission model or space station configuration, except when it was advantageous to present illustrative examples of the application of the data.

2.1.2 Selection Philosophy - Concepts and Techniques

The purpose of the study was to provide the spacecraft conceptual designer and the mission analyst basic data to:

- Assess the impact of waste generation and control on the mission
- Determine, in a quantitive manner, the waste products and their source of origin on the spacecraft
- Determine the desirability of onboard processing of the waste materials for utilization in lieu of resupply of consumables/expendables
- Select the equipments necessary for collection, transfer, sorting, processing for disposal, and disposal of waste products
- Assess the impact of waste control on spacecraft crew requirements and permit optimization studies between crew time requirements and equipments provided

This broad range of purposes made it necessary to provide information applicable to any forseeable spacecraft mission and not preselect equipments or procedures. Therefore, the data presented covers as broad a range as possible of waste sources, equipments, and manpower utilization procedures. It is the responsibility of the mission planner and spacecraft designer to assess the requirements and select the equipments and procedures to be used under any specific set of circumstances.

2.2 METHODOLOGY

Figure 2-1 represents the methodology used in performing the study. Three distinctive phases occurred, i.e., establishing the study input data, generating the study data, and preparing the data in report form. The following paragraphs explain the logic used in the performance of each of the tasks shown in the figure.

2.2.1 Perform Literature Survey

The literature survey was performed using both automated computer and manual searches. The sources of automated searches used were:

- Defense Documentation Center (DDC)
- Defense Logistics Studies Information Exchange
- NASA Tapes run on the FH/RAD IBM 7094 Computer

More specific manual searches were performed in particular areas of interest using many sources including:

- Monthly Catalogue of U.S. Government Publications
- U.S. Government Research and Development Reports
- Applied Science and Technology Index
- The Engineering Index
- Interdoc Directory of Published Proceedings
- Proceedings in Print

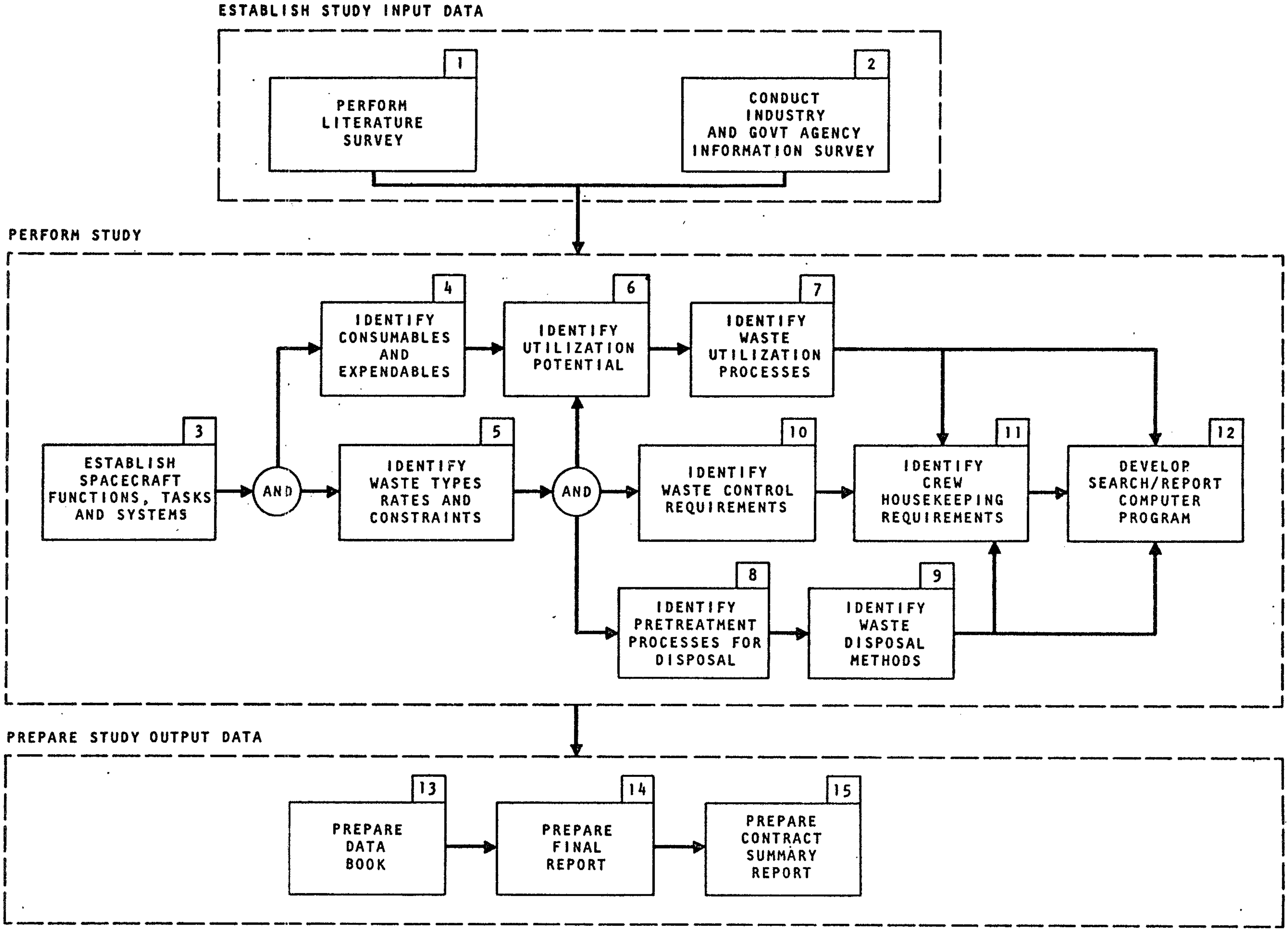

Figure 2-1. Study Methodology

2.2.2 Conduct Industry and Government Agency Information Survey

In addition to obtaining applicable documents as a result of the literature survey, a letter survey was conducted of companies and government agencies active in space research and development. The letter described the program in considerable detail and specified the areas in which information was desired under each of the tasks shown in Figure 2-1.

The response to this survey was excellent. Each of the following companies or agencies contributed significantly to the success of the study:

1) Government agencies, including:
   - Manned Spacecraft Center
   - Marshall Space Flight Center
   - Langley Research Center
   - Office of Manned Space Flight

2) Aerospace companies, including:
   - North American Rockwell - Space Division
   - McDonnell Douglas Astronautics Company - Space Station Program
   - General Dynamics Corporation - San Diego Division
   - Lockheed Missiles and Space Company - Research and Development Division
   - Grumman Astronautics Corporation - Space Station Program

2.2.3 Establish Spacecraft Functions, Tasks and Systems

To assure the incorporation of as broad a spectrum of data as possible under the definition of spacecraft wastes, a functional analysis was performed. Under the general catagories of supporting life, maintaining spacecraft operation, and the performance of mission tasks, the functions were derived to include as many areas as could be foreseen without definition of the spacecraft or its mission. Subsystems or laboratories were then defined in as broad a manner as possible to fulfill these functions. The equipments of the subsystems and the experiments to be performed in the laboratories were derived with as many alternatives as possible. These alternates formed the basis for the derivation of waste products. Approximately 220 candidate equipment definitions or potential man enhanced experiments resulted from this analysis. The results of this analysis is presented in Table 3.1-1.

An equipment or experiment operational description was prepared for each of the approximately 220 candidates along with schematic diagrams and the rationale for their operation, from which the consumables and expendables and the waste products could be derived. These operational descriptions are presented in Volume II of the Data Book.

2.2.4 Identify Consumables and Expendables

Based on the operational description of the candidate equipments/experiments, a listing of the potential consumables/expendables was prepared along with data on their rates of consumption and potential reclamation methods. These lists served two purposes. First, they formed the basis for deriving a large portion of the waste items because, in order to be consumed or expended, they must create by-products or be transformed in some manner into unuseful material. Secondly, these consumables/expendables form the shopping list of resupply items that must either be carried onboard during the initial launch or be logistically resupplied.

These lists of consumables/expendables are presented in Volume II of the Data Book along with the operational descriptions of their respective subsystem equipments and experiments.

2.2.5 Identify Waste Rates, Types, and Constraints

Again, the operational description formed the basis of derivation of the waste lists along with the background of having identified the consumables/expendables. Under the broad definition of waste, i.e., "those items that are no longer useful in their present form," failed parts from subsystems, crew metabolic wastes, contaminated water in any form, deceased crew members, the by-products of experiments not useful as data, etc., all become waste products.

In addition to identifying the wastes, interface information was generated to assist in subsequent studies of utilization processes, disposal methods, and housekeeping equipments and procedures. These interface data included:

1) Waste characteristics, state, and attributes- these included the waste state (solid, liquid, or gas), material descriptions (metals, plastics, organic, etc.), form factor (tubular, rod like, slurry, etc.), and other characteristics (sharp, radioactive, highly compressed, pathegenic, toxic, etc.) considered useful or necessary to those performing other parts of the study or the spacecraft and equipments designer. These data provided information and constraints for

other members of the study team covering utilization processes, disposal and housekeeping equipments and requirements.

2) Constituents and elements- constituents were identified as compounds (NH_4, CO_2, etc.), material, and trade names (steel, teflon, polyethelene, textile, etc.). Elements were identified by their chemical abbreviations (Cu, O_2, Fe, K, etc.). This information was supplied primarily for use by those studying the desirability and process requirements for utilization.

3) Rate data- information on the potential rate of production of the waste was generated. The data is presented in terms best describing the source or method of their generation. Man-dependent sources are presented for 12, 50, and 100 men stations; station operational equipment are presented as a 10-year total, daily rate, or unit weight. Experiment information is presented as experiment total, daily rate, and normal batch size. Again, this information is necessary for those studying utilization processing, disposal, and housekeeping equipment and requirements.

The preceding data is presented in detail in tabular form in Volume II of the Data Book.

2.2.6 Identify Utilization Potential

For a given spacecraft with prescribed manning, subsystems, and mission (experiments), it is possible to identify the consumables/expendables required over specific periods or the lifetime of the spacecraft. Likewise, it is possible to identify the waste products. Comparison of the constituents of the consumables/expendables and the waste products can show whether correlation exists. The desirability or advantage of replacing consumables/expendables with processed wastes is a matter of economics based primarily on the logistical problem of resupply and the lifetime cost of onboard processing, including the initial processor development, the cost of delivery of the processor to orbit, and the onboard operating cost.

Aspects of identifying the utilization potential is described in Section 3.4 of Volume I of the Data Book and Section 3.1.3 of this report.

2.2.7 Identify Waste Utilization Processes

The objective of any waste utilization process is to convert a potential waste product into onboard useable items. These can further be divided into the following two basic catagories:

1) Those applicable to generally recognized high-volume waste products and for which considerable effort and money has been spent in the past for the development of specific recovery processes, e.g., atmospheric CO_2 separation and reduction by the Bosch or Sabatier processes and water recovery through filtering, distillation, etc.
2) Those general catagories of processes based on generally accepted principles that can serve as basic building blocks in process development, e.g., physical separation (filtration, centrifugation, distillation, sorption), electrolysis, oxidation (incineration, wet oxidation), and decomposition (thermal, bacterial).

Data on both catagories was generated and prepared in the form of a summary sheet that shows basic data on the process principle, the material treated, consumables, process data on efficiency and power requirements, utility of products, and references for further data. Back up data containing more detailed information was also generated. Section 4.0 of Volume I of the Data Book contains the results of these analyses and the summary information is presented in Section 3.2 of this report.

2.2.8 Identify Pretreatment Processes for Disposal

Prior to disposal, processing the wastes will frequently be necessary to maintain a sterile condition, to deter the growth of organisms, to control odor, and to reduce bulk (compaction). The study was divided into three basic parts.

1) General microbial control for the general treatment of wastes--such as by the use of desiccation to prevent the growth of microbes present in the waste products
2) Microbial control for hospital or biological laboratories--such as by the use of dry or moist heat or chemicals such as ethelene oxide where pathogenic microorganisms could be present
3) Compaction and packaging--for those materials that have been processed and ready for disposal

Overlapping occurred for these pretreatment processes and those for utilization. For instance, the moist heat sterilizer (autoclave) can either be used for sterilization of bandages and agar jels to be disposed or for surgical instruments and glassware to be reused.

The data on pretreatment processes is presented in Section 5.0 of Volume I of the Data Book and summarized in Section 3.3 of this report.

2.2.9 Identify Waste Disposal Methods

Waste disposal was generally defined as the separation of waste products from the spacecraft. Candidate disposal means included return to earth via the shuttle, the use of rockets to separate waste containers for incineration in the earth's atmosphere or to alter the orbits, the use of incineration aboard the spacecraft, and the overboard jettisoning of waste products. Discussions and parametric data on these disposal methods are presented in Section 5.0 of Volume I of the Data Book and summarized in Section 3.2 of this report.

2.2.10 Identify Waste Control Requirements

Waste control is the collection, pickup, transfer, and sorting of waste products for either utilization or disposal processing. The collection process, defined as the initial placing of the waste item in the collection container, would cover all actions from the placing of soiled clothing in hampers to vacuum cleaning and cleansing the walls of the spacecraft. This study basically starts with the waste having been collected and awaiting pickup. The requirements for collection containers and conceptual designs were generated. Automated, manual assist, and all manual means of pickup, transfer, and sorting were studied, and conceptual designs are presented for a wide range of spacecraft sizes. The waste attributes contained in the waste definition tables of Volume II, as described in Section 2.2.5, formed the basis for deriving the processes and equipments requirements and constraints.

The results of these studies are presented in Section 6.0 of Volume I of the Data Book and are summarized in Section 3.4 of this report.

2.2.11 Identify Crew Housekeeping Requirements

Based on the definition of the waste sources, waste products, equipments for collection and transfer, utilization processors, and disposal means, a methodology for the assessment of crew functions and manhour and manpower requirements was derived. The rationale for assessing the variables due to zero and partial gravity and variables in the size of the crew as it effects housekeeping tasks was developed.

The basic approach was the generation of functional flow block diagrams for the tasks of pickup, transfer, and sorting. From the definition of these functions, housekeeping tasks were derived and further divided into task elements, which are discrete actions by the crew members. Time allocations can be assessed directly against these task elements. The summation of these times permits the computation of the manhour requirements for waste control and the allocation of crew members to the overall task of waste control.

These data and rationale are presented in Section 6.0 of Volume I of the Data Book and are summarized in Section 3.4 of this report. In addition, basic background information on human factor aspects of space flight and their interfaces with the tasks associated with waste control are presented.

2.2.12 Develop Search/Report Computer Program

The study generated a large body of data on the sources and quantities of waste materials, the equipments and manpower requirements for onboard handling and storage of this material, and the processes that can be used to recover and/or prepare for disposal the particular classes of wastes. These data are subject to updating as future spacecraft, subsystems, and missions are further defined. In addition, use of the data will require, among other things, search and retrieval of specific data items and sorting and collection of specific groups of data.

The development of a computer program to accomplish these tasks was undertaken during the course of the study. Section 7.0 of Volume I of the Data Book and Section 3.5 of this report present the capabilities of this program. Volume III of the Data Book includes a printout of the computer data presently stored in the data bank.

3.0 RESULTS OF STUDY

3.1 WASTE DEFINITION

The objective of the waste definition task was to define the magnitude of the waste control problem in order to establish the pertinent housekeeping requirements for various sizes of manned spacecraft in a near earth orbit. The work performed to satisfy the waste definition task has resulted in the following three major groups of information useful to the planners of future housekeeping systems:

- Compilation of waste sources
- Compilation of waste items
- Correlation of waste definition data to waste control requirements

3.1.1 Compilation of Waste Sources

A compilation of approximately 220 potential waste sources within a spacecraft has been made. The waste sources are envisioned as being the man and the various equipments necessary for the performance of the specific spacecraft functions. The waste sources are grouped by their functions and are shown in Table 3.1-1. There are three top level functions:

1) Support life
2) Maintain the spacecraft functions
3) Perform the mission tasks

These functions are further subdivided until the waste source is identified. Each waste source is identified by a five digit number that refers to a document in Volume II of the Data Book containing an operational description and an analysis of consumable/ expendables leading to the identification of the waste items from the waste source. The number is keyed to the functional analysis. A reference is supplied in Table 3.1-1 relating the waste source to its probable location or physical area on the spacecraft. The area names used have been coordinated with the area names supplied by NASA to the study contractor for the "Lighting, Acoustics, Temperature and Color Handbook (LATCH) for Extraterrestial Environments." The area names used are shown in Table 3.1-2.

TABLE 3.1-1 SPACECRAFT FUNCTIONS AND WASTE SOURCES

BASIC FUNCTION: 1.0 SUPPORT LIFE

FUNCTIONAL REQUIREMENT	SUBSYSTEM OR LABORATORY	EQUIPMENT OR EXPERIMENT (WASTE SOURCES)	OPERATIONAL DESCRIPTION DOCUMENT NUMBER	LOCATION BY SPACECRAFT AREA
1.1 Maintain and Monitor Crew Health and Safety	1. Medical Dispensary	1. Routine Examination of Crew Members	1.1.1.1.1	Services: Dispensary
		2. Illness Event	1.1.1.2.1	
	2. Dental Dispensary	1. Routine Examination and Illness Event	1.1.2.1.1	Services: Dispensary
	3. Dispensary Housekeeping	1. Medical	1.1.3.1.1	Services: Maintenance
		2. Dental	1.1.3.2.1	
	4. Personnel Protection	1. Space Suits and Portable Life Support Systems	1.1.4.1.1	Services: Airlocks
1.2 Provide Crew Quarters	1. Provide Furnishings	1. Room Furnishings	1.2.1.1.1	Living Area; Bed Room
	2. Provide Personal Articles	1. Clothing	1.2.2.1.1	Living Area; Bed Room
		2. Bed Linens	1.2.2.2.1	Living Area; Bed Room
		3. Limited Personal Grooming Facility	1.2.2.3.1	Living Area; Bed Room
	3. Rest and Relaxation Provisions	1. Individual Crew Recreation	1.2.3.1.1	Living Area; Recreation Living Area; Study/Library
1.3 Provide Crew Meals	1. Food Storage System	1. Perishable Food Storage		Food Preparation and Service; Storage and Kitchen
		a) Perishable Food Storage - Mechanical	1.3.1.1.1	
		b) Perishable Food Storage - Thermoelectric	1.3.1.1.2	
		c) Perishable Food Storage - Space Radiator	1.3.1.1.3	
		2. Stable Food Storage	1.3.1.2.1	Food Preparation and Service; Storage and Kitchen
	2. Food and Food Preparation	1. Food Reconstitution		Food Preparation and Service; Kitchen and Snack Bar
		a) Food Reconstitution - Rehydration	1.3.2.1.1	
		b) Food Reconstitution - Heating	1.3.2.1.2	
		2. Meal Assembly	1.3.2.2.1	Food Preparation and Service; Kitchen
	3. Meal Service and Dining	1. Meal and Accessory Transport	1.3.3.1.1	Food Preparation and Service; Dining Area
		2. Dining	1.3.3.2.1	Food Preparation and Service; Dining Area and Snack Bar

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TABLE 3.1-1 SPACECRAFT FUNCTIONS AND WASTE SOURCES (Cont'd.)

BASIC FUNCTION: 1.0 SUPPORT LIFE (Cont'd)				
FUNCTIONAL REQUIREMENT	SUBSYSTEM OR LABORATORY	EQUIPMENT OR EXPERIMENT (WASTE SOURCES)	OPERATIONAL DESCRIPTION DOCUMENT NUMBER	LOCATION BY SPACECRAFT AREA
1.3 Provide Crew Meals	4. Housekeeping	1. Debris Collection		
		a) Debris Control - Mechanical	1.3.4.1.1	Food Preparation and Service; Kitchen, Dining Area and Snack Bar
		b) Debris Control - Manual	1.3.4.1.2	
		2. Utensil Cleansing	1.3.4.2.1	Food Preparation and Service; Kitchen
		3. Waste Stowage	1.3.4.3.1	Food Preparation and Service; Kitchen, Dining Area, Snack Bar
1.4 Provide for Crew Hygiene	1. Human Waste Management	1. Fecal and Vomitus Waste Management		
		a) Integrated Vacuum Drying	1.4.1.1.1	Living Area; Bathroom; Services; Dispensary
		b) Automated Bag/Vacuum Drying	1.4.1.1.2	" "
		c) Wet Collection/Processing	1.4.1.1.3	" "
		2. Urine Collection	1.4.1.2.1	" "
	2. Full Body Wash	1. Body Wash		
		a) Shower	1.4.2.1.1	Living Area; Bathroom
		b) Immersion Bath	1.4.2.1.2	Living Area; Bathroom
		c) Automated Sponge Bath	1.4.2.1.3	Living Area; Bathroom
	3. Partial Body Wash and Personal Grooming	1. Hygiene Center	1.4.3.1.1	Living Area; Bathroom
	4. Revitalization of Textiles	1. Laundry	1.4.4.1.1	Services; Laundry
	5. Crew Quarters Housekeeping Capability	1. Vacuum Cleaner	1.4.5.1.1	Services; Maintenance
		2. Surface Washer/Wiper (Automated Mop)	1.4.5.2.1	Services; Maintenance
1.5 Environmental Control/Life Support	1. Atmospheric Gas Supply	1. Supercritical Storage and Supply	1.5.1.1.1	Services; Storage
	2. Atmospheric Control	1. Atmospheric Mixing and Pressure Control	1.5.2.1.1	Services; Storage

TABLE 3.1-1 SPACECRAFT FUNCTIONS AND WASTE SOURCES (Cont'd.)

BASIC FUNCTION: 1.0 SUPPORT LIFE (Cont'd)				
FUNCTIONAL REQUIREMENT	SUBSYSTEM OR LABORATORY	EQUIPMENT OR EXPERIMENT (WASTE SOURCES)	OPERATIONAL DESCRIPTION DOCUMENT NUMBER	LOCATION BY SPACECRAFT AREA
1.5 Environmental Control/Life Support	3. Atmospheric Temperature and Humidity Control	1. Variable Speed Fan System	1.5.3.1.1	Services; Equipment
	4. Trace Contaminant Removal System	1. Regenerable Charcoal/Catalytic Oxidation System	1.5.4.1.1	Services; Equipment
	5. Bacterial/Particulate Control System	1. Direct Storage Method	1.5.5.1.1	Services; Equipment
		2. Sterilization/Storage Method	1.5.5.2.1	Services; Equipment
	6. Carbon Dioxide Control and Oxygen Generation	1. CO_2 Removal/Concentration Systems	1.5.6.1.1	Services; Equipment
		2. CO_2 Reduction System	1.5.6.2.1	Services; Equipment
		3. Water Electrolysis System	1.5.6.3.1	Services; Equipment
	7. Thermal Transport Circuit	1. Coolant Loop	1.5.7.1.1	Services; Equipment
	8. Water Management	1. Water Reclamation System	1.5.8.1.1	Services; Equipment
		2. Potable Water Storage System	1.5.8.2.1	Services; Equipment

TABLE 3.1-1 SPACECRAFT FUNCTIONS AND WASTE SOURCES (Cont'd.)

BASIC FUNCTION: 2.0 MAINTAIN SPACE CRAFT FUNCTION

FUNCTIONAL REQUIREMENT	SUBSYSTEM OR LABORATORY	EQUIPMENT OR EXPERIMENT (WASTE SOURCES)	OPERATIONAL DESCRIPTION DOCUMENT NUMBER	LOCATION BY SPACECRAFT AREA
2.1 Control Spacecraft Orbit Position, Attitude and Motion	1. Nav. Guid, Stabilization and Control	1. Electronic Systems	2.1.1.1.1	Work Area;Communications Extra Vehicular
		2. Mechanical Systems		
		a) Control Moment Gyros	2.1.1.2.1	Work Area; Control
		b) Reaction Jet Control, Mono-Propellant	2.1.1.2.2	Services; Equipment and Extra Vehicular
		c) Reaction-Jet Control, Bi-Propellant	2.1.1.2.3	Services; Equipment and Extra Vehicular
2.2 Provide Electrical and Thermal Power	1. Electric Power	1. Solar Arrays	2.2.1.1.1	Extra Vehicular
		2. Radioisotope Brayton Cycle	2.2.1.2.1	Extra Vehicular
	2. Regulate Power	1. Power Conditioning System	2.2.2.1.1	Services; Power
	3. Distribute Power	1. Power Distribution System	2.2.3.1.1	Services; Power
2.3 Maintain and Repair Space Craft	1. Maintenance Facilities	1. Structural Maintenance	2.3.1.1.1	Services; Maintenance
		2. Avionics Systems Maintenance	2.3.1.2.1	Services; Maintenance
		3. Utilities Maintenance	2.3.1.3.1	Services; Maintenance
2.4 Provide Communication	1. Ship-to-Base Communications	1. To and From Ground - Data Relay Space Satellites	2.4.1.1.1	Work Areas; Communications
		2. To and From Ground - Direct	2.4.1.2.1	Work Areas; Communications
	2. Inter-Vehicular Communications	1. To and From Experiment Modules	2.4.2.1.1	Work Areas; Communications
		2. To and From Space Station Shuttle	2.4.2.2.1	Work Areas; Communications
		3. Extra-Vehicular Communications	2.4.2.3.1	Work Areas; Communications
	3. Intra-Vehicular Communications	1. Onboard Communications	2.4.3.1.1	Work Areas; Communications
2.5 Provide for Data Management	1. Data Collection, Storage and Display	1. Data Management-Electronic	2.5.1.1.1	Work Area; Computer
		2. Data Management - Photographic	2.5.1.2.1	Work Area; Photographic Support
2.6 Provide for Spacecraft Logistics	*			
2.7 Provide for Experiment Support	*			

* These areas not reviewed during the performance of this study due to the lack of definitive plans for future programs.

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REPUBLIC AVIATION DIVISION

TABLE 3.1-1 SPACECRAFT FUNCTIONS AND WASTE SOURCES (Cont'd.)

BASIC FUNCTION: 3.0 PERFORM MISSION TASKS				
FUNCTIONAL REQUIREMENT	SUBSYSTEM OR LABORATORY	EQUIPMENT OR EXPERIMENT (WASTE SOURCES)	OPERATIONAL DESCRIPTION DOCUMENT NUMBER	LOCATION BY SPACECRAFT AREA
3.1 Astronomy, Astrophysics and Celestial Mechanics Studies and Tasks	1. Astronomy and Astrophysics	1. Plasma Physics (FPE 5.7)		
		a) Ionospheric Spacecraft Wake Experiment	3.1.1.1.1 VOID (See 3.2.1.1.1)	
		2. Grazing Incidence X-Ray Telescope (FPE 5.1)		
		a) Polarization of X-Radiation	3 1.1 2 1	Remote Module
		b) Curved Crystal X-Ray Spectrometer	3.1.1.2.2	Remote Module
		c) High Resolution Studies of X-Ray Sources	3.1.1.2.3	Remote Module
		d) Maximum Sensitivity X-Ray Detector	3.1 1.2.4	Remote Module
		3. High Energy Stellar Astronomy (FPE 5.5)		
		a) X-Ray Imaging	3.1.1.3.1	Remote Module
		b) Bragg Spectrometer	3.1.1.3.2	Remote Module
		c) Spark Chamber, Nuclear Emulsion Gamma-Ray	3.1.1.3.3	Astronomy Module
		d) Nuclear Gamma-Ray Spectrometer	3.1.1.3.4	Astronomy Module
		4. UV Stellar Survey (FPE 5.4)		
		a) Schmidt Image Converter Stellar Spectrograph	3.1.1.4.1	Astronomy Module
3.2 Physics and Chemistry Studies and Tasks	1. Physics	1. Plasma Physics (FPE 5.7)		
		a) Plasma Wake Experiments	3.2.1.1.1	Work Area: Laboratory and Remote Satellite
		b) Cyclotron Harmonic Wave Transmission Experiment	3.2.1.1.2	Work Area: Laboratory and Remote Satellite
		2. Cosmic Ray Physics (FPE 5.8)		
		a) Interaction Physics Experiments (Bay 1)	3.2.1.2.1	Work Area: Airlock and Attached Module
		b) High Energy Primary Cosmic Ray Experiment (Bays 2 and 3)	3.2.1.2.2	Work Area: Airlock and Attached Module
	2. Chemistry	1. Unit Separation Processes in Space	3.2.2.1.1	Work Area: Laboratory
		2. Industrial Microbiological Applications in O G		Work Area: Laboratory
		a) A Vaccine Satellite Program	3.2.2.2.1	

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TABLE 3.1-1 SPACECRAFT FUNCTIONS AND WASTE SOURCES (Cont'd.)

BASIC FUNCTION: 3.0 PERFORM MISSION TASKS (Cont'd)

FUNCTIONAL REQUIREMENT	SUBSYSTEM OR LABORATORY	EQUIPMENT OR EXPERIMENT (WASTE SOURCES)	OPERATIONAL DESCRIPTION DOCUMENT NUMBER	LOCATION BY SPACECRAFT AREA
3.3 Agriculture and Animal Husbandry	1. Plant Crops	1. Rapid Lettuce Growth	3.3.1.1.1	Work Area: Agricultural Study Area, Remote Dockable Module
		2. No Waste Food (Radish/Cabbage)	3.3.1.2.1	Work Area: Agricultural Study Area, Remote Dockable Module
		3. Increased CO_2 on Food Plants	3.3.1.3.1	Work Area: Agricultural Study Area, Remote Dockable Module
	2. Animal Crops	1. Japanese Quail (Colinus)	3.3.2.1.1	Work Area: Animal Housing
3.4 Biological Sciences and Biotechnology Studies	1. Micro Biology Experiment (BIO C)(FPE 5.25)	1. The Role of Gravity in General Cellular Function		Work Area:BIO-Laboratory
		a) General Growth Behavior and Reproduction in Cells	3.4.1.1.1	
		b) Maintenance of Normal Growth and Reproduction in Free Cells	3.4.1.1.2	
		c) Mineral Metabolism in Cells	3.4.1.1.3	
		2. Genetic Stability in Free Cells	3.4.1.2.1	Work Area:BIO-Laboratory
		3. The Role of Gravity in Tissue Function		Work Area:BIO-Laboratory
		a) Animal Tissue Development	3.4.1.3.1	
		b) Plant Tissue Development	3.4.1.3.2	
		4. Development in the Animal Embryo	3.4.1.4.1	Work Area:BIO-Laboratory
		5. Host-Parasite Relationships	3.4.1.5.1	Work Area:BIO-Laboratory
		6. Biorythms in Microorganisms	3.4.1.6.1	Work Area:BIO-Laboratory
		7. Weightlessness and Molecular Reactions in Vitro	3.4.1.7.1	Work Area:BIO-Laboratory
	2. Invertebrates Experiments (BIO F)(FPE 5.26)	1. The Invertebrate Organism and Its Life Cycle	3.4.2.1.1	
		2. The Role of Gravity in Morphogenesis	3.4.2.2.1	
		3. The Role of Gravity in Invertebrate Metabolism	3.4.2.3.1 VOID (See 3.4.2.1.1)	
		4. The Role of Gravity in Aging in Invertebrates	3.4.2.4.1	

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TABLE 3.1-1 SPACECRAFT FUNCTIONS AND WASTE SOURCES (Cont'd.)

BASIC FUNCTION: 3.0 PERFORM MISSION TASKS (cont'd)

FUNCTIONAL REQUIREMENT	SUBSYSTEM OR LABORATORY	EQUIPMENT OR EXPERIMENT (WASTE SOURCES)	OPERATIONAL DESCRIPTION DOCUMENT NUMBER	LOCATION BY SPACECRAFT AREA
3.4 Biological Sciences and Biotechnology Studies (continued)	2. Invertebrates Experiments (BIO F)(FPE 5.26)	5. Genetic Phenomina in Invertebrates		Work Area: BIO-Laboratory
		a) Mutability in Adult Drosophila	3.4.2.5.1	
		b) Radiation Repair Mechanisms in Chromosomes	3.4.2.5.2	
		6. Biorythmicity in Invertebrates		Work Area: BIO-Laboratory
		a) Circadian Rythms in Invertebrates	3.4.2.6.1	
		b) Biorythmicity in Fiddler Crabs	3.4.2.6.2	
		7. Behavior Influences in Invertebrates		Work Area: BIO-Laboratory
		a) Behavior Influences in Bees	3.4.2.7.1	
		b) Orientation and Geosensing in Spiders	3.4.2.7.2	
	3. Small Vertebrates Experiments (BIO D) (FPE 5.9)	1. The Role of Gravity in Cardiovascular Function	3.4.3.1.1	Work Area: BIO-Laboratory/ Animal Housing
		2. The Life Cycle of Rodents		Work Area: BIO-Laboratory/ Animal Housing
		a) Pregnancy and Growth in the Mammalian Organism	3.4.3.2.1	
		b) Physiology and Behavior Through One Generation	3.4.3.2.2	
		c) Turnover of Mineralized Tissue	3.4.3.2.3	
		d) Metabolic Adaptation of the Mammalian Organism	3.4.3.2.4	
		3. Immune Responses of Mammals		Work Area: BIO-Laboratory/ Animal Housing
		a) Mobile Cells and Muco Proteins	3.4.3.3.1	
		b) Production and Persistance of Circulating Anti-Bodies	3.4.3.3.2	
		4. Embryogenesis and Development in Amphibia	3.4.3.4.1	Work Area: BIO-Laboratory/ Animal Housing
		5. Growth and Metabolism in Reptiles	3.4.3.5.1	Work Area: BIO-Laboratory/ Animal Housing
		6. Influence of Gravity on Behavior in Mammals	3.4.3.6.1	Work Area: BIO-Laboratory/ Animal Housing
		7. Influence on Biorythms of Animals	3.4.3.7.1	Work Area: BIO-Laboratory/ Animal Housing
		8. The Role of Gravity in Hibernation	3.4.3.8.1	Work Area: BIO-Laboratory/ Animal Housing

TABLE 3.1-1 SPACECRAFT FUNCTIONS AND WASTE SOURCES (Cont'd.)

BASIC FUNCTION: 3.0 PERFORM MISSION TASKS (Cont'd)

FUNCTIONAL REQUIREMENT	SUBSYSTEM OR LABORATORY	EQUIPMENT OR EXPERIMENT (WASTE SOURCES)	OPERATIONAL DESCRIPTION DOCUMENT NUMBER	LOCATION BY SPACECRAFT AREA
3.4 Biological Sciences and Bio-technology Studies (continued)	4. Plant Specimens (BIO E) (FPE 5.10)	1. Plant Responses from 0 to 1 G	3.4.4.1.1	Work Area, Agricultural Study Area or Remote Dockable Module
		2. Pea Seedling Growth in Orbit	3.4.4.2.1	Work Area, Agricultural Study Area or Remote Dockable Module
		3. Plant Morphogenesis Under Weightlessness	3.4.4.3.1	Work Area, Agricultural Study Area or Remote Dockable Module
		4. Effect of Weightlessness on Gamotogenesis and Morphogenesis of Pterjs Gametophytes	3.4.4 4.1	Work Area, Agricultural Study Area or Remote Dockable Module
		5. Role of Auxin Mediated Reactions in the Developing Wheat Seedling in O G	3.4.4.5.1	Work Area, Agricultural Study Area, Remote Dockable Module
		6. Role of Gravitational Stress in Land Plant Evolution	3.4.4.6.1	Work Area, Agricultural Study Area or Remote Dockable Module
		7. Effect of Geophysical Factors on Circadian Rhythms in Plants	3.4.4.7.1	Work Area, Agricultural Study Area or Remote Dockable Module
		8. Algae, Duckweed in 0 G	3.4.4.8.1	Work Area, Agricultural Study Area or Remote Dockable Module
	5. Primates	1. Physiology of Chimpanzees in Orbit	3 4.5.1.1	Work Area, Animal Housing
		2. Hemodynamics and Metabolic Effects on Monkeys	3.4.5.2.1	Work Area, Animal Housing
3.5 Biotechnology and Human Research	1. Biomedical Research (FPE 5.13)	1. Neurophysiology		Work Area: Medical Laboratory
		a) Effect of Head Movement During Rotation	3.5.1.1.1	
		b) Sensitivity of Otolith and Semi-Circular Canal Mechanisms	3.5.1.1.2	
		c) Effect of Altered Day-Night Cycles, Effect on Litter Size, and on EEG of Cats	3.5.1.1.3	
		d) Human Vestibular Function	3.5.1.1.4	
		2. Cardiovascular		Work Area: Medical Laboratory
		a) Changes in Circulatory Response to Exercise	3.5.1.2.1	
		b) Effect of Blood Distribution on Arterial Pressure Control Systems	3.5.1.2.2	
		c) Alterations in Venous Compliance Due to the Absence of Hydrostatic Pressure	3.5.1.2.3	
		d) Cardiac Dynamics	3.5.1.2.4	

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TABLE 3.1-1 SPACECRAFT FUNCTIONS AND WASTE SOURCES (Cont'd.)

BASIC FUNCTION: 3.0 PERFORM MISSION TASKS (Cont'd)

FUNCTIONAL REQUIREMENT	SUBSYSTEM OR LABORATORY	EQUIPMENT OR EXPERIMENT (WASTE SOURCES)	OPERATIONAL DESCRIPTION DOCUMENT NUMBER	LOCATION BY SPACECRAFT AREA
3.5 Biotechnology and Human Research (continued)	1. Biomedical Research (FPE 5.13) (continued)	2. Cardiovascular (cont'd)		Work Area: Medical Laboratory
		e) Intraocular Arterial Blood Pressure	3.5.1.2.5	
		f) Cardiac Output. Direct versus Indirect	3.5.1.2.6	
		g) Use of a LBNP Device to Prevent C.V. Deconditioning	3.5.1.2.7	
		h) *Use on an On-Board Centrifuge to Prevent C.V. Deconditioning*	3.5.1.2.8	
		i) Use of Occlusive Cuffs to Prevent C.V. Deconditioning	3.5.1.2.9	
		j) C.V. Response to Shock Therapy	3.5.1.2.10	
		k) Sensitivity of the Carotid Sinus-Arterial Pressure Control Loop	3.5.1.2.11	
		l) Peripheral Arterial Reactivity	3.5.1.2.12	
		m) Changes in Blood Volume and Distribution	3.5.1.2.13	
		n) Carotid Baroreceptor Electrical Activity in Primates	3.5.1.2.14	
		3. Respiration		Work Area: Medical Laboratory
		a) Pulmonary Mechanics	3.5.1.3.1	
		b) Respiratory Control	3.5.1.3.2	
		c) Blood and Ventilatory Gas Exchange	3.5.1.3.3	
		d) Lung Cleaning in Rats	3.5.1.3.4	
		e) Induced Pulmonary Infection in Mice	3.5.1.3.5	
		f) Recovery Rate from Non-Infectious Trauma in Rats	3.5.1.3.6	
		4. Gastrointestinal		Work Area: Medical Laboratory
		a) G.I. Motility and pH	3.5.1.4.1	
		b) Intestinal Absorption	3.5.1.4.2	
		c) Indices of Renal Function	3.5.1.4.3	
		d) Renal Calculus Formation in Rats	3.5.1.4.4	
		e) Renal Infection in Rats	3.5.1.4.5	
		5. Metabolism and Nutrition		Work Area: Medical Laboratory
		a) Energy Metabolism	3.5.1.5.1	
		b) Carbohydrate and Fat Metabolism	3.5.1.5.2	
		c) Protein Metabolism	3.5.1.5.3	
		d) Fluid and Electrolyte Balance	3.5.1.5.4	
		e) Mineral Metabolism	3.5.1.5.5	
		f) Bioassay of Body Fluids	3.5.1.5.6	

TABLE 3.1-1 SPACECRAFT FUNCTIONS AND WASTE SOURCES (Cont'd.)

BASIC FUNCTION: 3.0 PERFORM MISSION TASKS (Cont'd)

FUNCTIONAL REQUIREMENT	SUBSYSTEM OR LABORATORY	EQUIPMENT OR EXPERIMENT (WASTE SOURCES)	OPERATIONAL DESCRIPTION DOCUMENT NUMBER	LOCATION BY SPACECRAFT AREA
3.5 Biotechnology and Human Research (continued)	1. Biomedical (FPE 5.13)(continued)	6. Musculoskeletal		Work Area: Medical Laboratory
		a) Bone Density	3.5.1.6.1	
		b) Fracture Healing in Animals	3.5.1.6.2	
		c) Calcium Mobilization	3.5.1.6.3	
		d) Muscle Mass and Strength	3.5.1.6.4	
		e) Induction of Pressure Atrophy	3.5.1.6.5	
		f) Electromyography as an Index of Deconditioning	3.5.1.6.6	
		g) Specimen Mass Measurement	3.5.1.6.7	
		7. Endocrinology		Work Area: Medical Laboratory
		a) Endoctrine Function and Stress Physiology	3.5.1.7.1	
		b) Temperature Regulation Mechanisms	3.5.1.7.2	
		c) Adrenal and Parathyroid Functions in Rats	3.5.1.7.3	
		d) Gonad Histopathology	3.5.1.7.4	
		8. Hematology		Work Area: Medical Laboratory
		a) Leukocyte Replication	3.5.1.8.1	
		b) Blood Cell Dynamics - Erythrocyte	3.5.1.8.2	
		c) Leukocyte Dynamics	3.5.1.8.3	
		d) Platelet Dynamics	3.5.1.8.4	
		e) Leukocyte Mobilization in Mice after Chemical Challenge	3.5.1.8.5	
		f) Maximum Rate of Erythrocyte Production in Rats	3.5.1.8.6	
		g) Wound Healing	3.5.1.8.7	
		h) Blood Coagulation and Hemostatic Function	3.5.1.8.8	
		i) Cytogenetic Studies	3.5.1.8.9	
		j) Blood Volume and Red Cell Life Span	3.5.1.8.10	
		9. Microbiology and Immunology		
		a) Microbiological Evaluation of Surfaces	3.5.1.9.1	All Surfaces
		b) Microbial Profiles of Crew Members	3.5.1.9.2	Work Area: Microbiology Laboratory
		c) Air Sampling for Microorganisms	3.5.1.9.3	All Areas
		d) Immunological Survey of Crew Members	3.5.1.9.4	Work Area: Medical Laboratory
	2. Man-Systems Integration (FPE 5.14)	1. Space Systems Human Factors		Work Area: Laboratory
		a) Restraint and Fine-Force Generation	3.5.2.1.1	
		b) Restraint and Gross Force Generation	3.5.2.1.2	
		c) Psychomotor Functions	3.5.2.1.3	
		d) Volume and Layout of Crew Work and Rest Areas and Modifications	3.5.2.1.4	

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TABLE 3.1-1 SPACECRAFT FUNCTIONS AND WASTE SOURCES (Cont'd.)

BASIC FUNCTION: 3.0 PERFORM MISSION TASKS (Cont'd)				
FUNCTIONAL REQUIREMENT	SUBSYSTEM OR LABORATORY	EQUIPMENT OR EXPERIMENT (WASTE SOURCES)	OPERATIONAL DESCRIPTION DOCUMENT NUMBER	LOCATION BY SPACECRAFT AREA
3.5 Biotechnology and Human Research (continued)	2. Man-Systems Integration (FPE 5.14) (continued)	e) Interior Design	3.5.2.1.5	All Areas
		f) Clothing	3.5.2.1.6	Ad Lib
		g) Interpersonal Factors	3.5.2.1.7	Work Area:Communications
		h) Recreation	3.5.2.1.8	Living Area: Recreation
		2. EVA/IVA Technology		
		a) Orientation, Stability and Restraint	3.5.2.2.1	Ad Lib
		b) Personnel Translation	3.5.2.2.2	E.V.A. + Ad Lib
		c) Mass Translation	3.5.2.2.3	Ad Lib
		d) Protective Clothing and Advanced Space Suit Assembly Development	3.5.2.2.4	EVA
		e) IVA Suit (Partial Pressure)	3.5.2.2.5	Work Area: Laboratory Work Area: Airlock
		3. Maintenance and Maintainability		
		a) Accessibility	3.5.2.3.1	Various Areas
		b) Maintenance and Repair in Zero G	3.5.2.3.2	All Areas
		4. Behavior		
		a) Intrapersonal Factors	3.5.2.4.1	Work Area: Psychology Laboratory
		b) Visual Function	3.5.2.4.2	Work Area: Psychology Laboratory
		c) Communications and Recording	3.5.2.4.3	Work Area: Psychology Laboratory Work Area: Control
		d) Kinesthetic Function	3.5.2.4.4	Work Area: Psychology Laboratory Work Area: Control
		e) Orientation Senses	3.5.2.4.5	Work Area: Psychology Laboratory Work Area: Control
		f) Chemical Sense Function	3.5.2.4.6	Work Area: Psychology Laboratory Work Area: Control
		g) Somesthetic Function	3.5.2.4.7	Work Area: Psychology Laboratory Work Area: Control
		h) Intellectual Function	3.5.2.4.8	Work Area: Psychology Laboratory Work Area: Control
		i) Higher Mental Function	3.5.2.4.9	Work Area: Psychology Laboratory Work Area: Control
		j) Auditory Function	3.5.2.4.10	Work Area: Psychology Laboratory Work Area: Control

TABLE 3.1-1 SPACECRAFT FUNCTIONS AND WASTE SOURCES (Cont'd.)

BASIC FUNCTION: 3.0 PERFORM MISSION TASKS (Cont'd)

FUNCTIONAL REQUIREMENT	SUBSYSTEM OR LABORATORY	EQUIPMENT OR EXPERIMENT (WASTE SOURCES)	OPERATIONAL DESCRIPTION DOCUMENT NUMBER	LOCATION BY SPACECRAFT AREA
3.6 Space Manufacturing Studies and Tasks	1. Materials Melting (FPE 5.16)	1. Minimum Batch Size	3.6.1.1.1	Work Area: Melting Laboratory
	2. Materials Processing (FPE 5.16)	1. Medium Batch Size	3.6.2.1.1	Work Area: Melting Laboratory
	3. Pre-Production Materials Processing (FPE 5.24)	1. Pre-Production Lots	3.6.3.1.1	Work Area: Laboratory
	4. Production Materials Processing (FPE 5.24)	1. Manufacturing and Processing Facility	3.6.4.1.1	Work Area: Laboratory
3.7 Earth Surveys	1. Earth Resources and Meteorology (FPE 5.11)	1. Agriculture/Forestry and Geography Experiments	3.7.1.1.1	Earth Observations Laboratory
		2. Geology/Minerology Experiments	3.7.1.2.1	Earth Observations Laboratory
		3. Hydrology/Water Resources Experiments	3.7.1.3.1	Earth Observations Laboratory
		4. Meterology Experiments	3.7.1.4.1	Earth Observations Laboratory
		5. Oceanography Experiments	3.7.1.5.1	Earth Observations Laboratory
3.8 Advanced Technology and Engineering Operations		NOTE: These areas not reviewed during the performance of this study due to lack of definite plans for future programs		
3.9 Lunar and Interplanetary Mission Support	1. Lunar Missions	1. Astronomical Investigations	3.9.1.1.1	Work Area: Laboratory and Storage
		2. Geological Explorations	3.9.1.2.1	Work Area: Laboratory and Storage
3.10 Military Sciences		NOTE: Not further reviewed due to classified nature of material		

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TABLE 3.1-2
SPACECRAFT ARCHITECTURAL AREAS

LIVING AREAS -

- Lounge
- Recreation
- Halls, Stairways, and Elevators
- Bathroom
- Bedroom
- Study/Library

SERVICES -

- Dispensary (medical and dental)
- Laundry
- Supply
- Maintenance
- Power
- Equipment
- Barber
- Chapel
- Airlocks
- Storage
- Gym

FOOD PREPARATION AND SERVING -

- Kitchen
- Dining Room
- Food Storage
- Snack Bar

WORK AREAS -

- Control
- Communications
- Computer
- *Laboratory (all types)
- Shops (mechanical, electrical, chemical)
- Offices
- Inspection
- Docking (shipping and receiving)
- Photographic Support
- Animal Housing
- Agricultural Study Area
- Airlocks

ADDITIONAL AREAS -

- EVA (local to spacecraft)
- External (shuttle)
- Remote Module - other dockable spacecraft - separate
- Attached Module - other dockable spacecraft - attached

*LABORATORIES -

- Agricultural Studies
- Bio-Lab
- Medical
- Astronomy
- Etc.

3.1.2 Compilation of Waste Items

Each of the over 220 waste sources was analyzed for the potential waste products that would result from the operation of the equipment that made up that waste source. The analysis includes an operational description, a list of consumable/expendables and a list of waste items. The list of consumable/expendables was examined and analyzed for the waste products that would result.

The waste items represent the raw materials from which new consumable/expendables potentially can be derived. This utilization potential of wastes can be related to a rate of waste generation or to a rate of consumption. Preliminary analysis indicates the break-even point between the cost of resupplying the consumables and the cost of on-board processing to utilize the waste products can lie somewhere between 39 and 570 lbs/month, with the most reasonable single number being around 100 lbs/month. Volume II of the Data Book includes copies of all the analyses of all the waste sources and individual lists of consumables/expendables and lists of waste items that result therefrom. Table 3.1-3 is a compilation of those consumables/expendables and wastes whose consumption and generation rate is sufficiently high to warrant future investigation for an on-board waste utilization process to reduce resupply requirements.

3.1.3 Correlation of the Waste Definition Data to Waste Control Requirements

Each of the waste items identified was analyzed for its potential impact on the housekeeping routines and on the waste/control utilization requirements. It is considered useful to include specific waste definition data or waste characteristics on the waste lists in addition to the identification and generation data. The form of the waste definition data has been selected to allow interfacing of the waste items to the various housekeeping equipments and routines being considered and to the utilization process candidates. The definition of the waste is contained on the waste lists previously described. The definition of the waste consists of the information under the following headings and allows interfacing of the waste with the waste control functions as indicated.

HEADING	CONTENTS	INTERFACE FUNCTION
STATE	Liquid, Solid, Gas	Handling, Disposal
ATTRIBUTES	Material Types	Utilization, Disposal
	Form Factors	Collection, Transfer Pretreatment, Disposal
	Constraints	Pretreatment, Collection Disposal
CHEMICAL COMPOSITION	Elements, Compounds	Utilization
ACTION REQUIRED TO RECLAIM	Wash, Sterilize Condense, Strain, Vacuum Desorb, Reverse Flush, Repair, Etc.	Reclamation

TABLE 3.1-3
HIGH RATE ITEMS -- 12 MAN CREW

ITEM	Approx. Rate (lbs/month)	CATEGORY			Waste Utilization Potential
		Consum - able	Expend- able	Waste Item	
Nitrogen Leakage	50	X			Derive from decomposition of Nitrogenous Material (Feces, NH_3)
Oxygen	720	X			Derive from CO_2 reduction or electrolosis of water
CO_2	750			X	Source of O_2 & C
Food (reconstituted meals)	1700	X			Derive from chemical/biological conversion of mineral & organic wastes
Food Discards	250			X	Source of nitrogen for fertilizer or as N_2 makeup.
Food Packaging	420			X	Compact & convert to building blocks for biowell external structural member or internal partitions
Fecal Material	138			X	Fertilizer or N_2 source
Water (food, drink)	2000	X			Manufacture from atmospheric moisture or urine
Water (washing)	3000		X		Reclaim by reverse osmosis or multifiltration with bacterial control
Urine	800			X	Source for potable H_2O, N_2
Cooking/Eating Utensils	1000		X	X	Wash
Clothes, Bedding, Towelling	500		X	X	Launder
Li OH (for EVA)	50	X		X	Replace with reversible process
Batteries (for EVA)	50		X	X	Recharge
Atmospheric Moisture	100			X	Source of potable water, O_2
Atmospheric Sorbants	120	X	X	X	Heat &/or vacuum reactivation or replace with reversible process

TABLE 3.1-3 (Continued)
HIGH RATE ITEMS - 12 MAN CREW

ITEM	Approx. Rate (lbs/Month)	CATEGORY			Waste Utilization Potential
		Consumable	Expendable	Waste Item	
Mechanical Filters, Wicks	100		X	X	Reverse flush, wash, sterilize
Film (photographic)	210	X			No feasible process known
Photographic Chemicals	210		X	X	Filter & reverse chemical action
Photographic Remnants	254			X	Compact & convert to building blocks for biowell, external structural member or internal partitions.
AGAR Gel	100		X	X	Boil & filter
Hyperdermics, Biological/Chemical Glassware & Utility Surfaces	100		X	X	Sterilize and wash
Wipes	72		X	X	Sterilize and launder
Failed Electrical/Mechanical Items	80		X	X	Repair, cannibalize for spares
Battery Charger Regulators	140		X	X	Repair, cannibalize for spares

Additional interface information that can be used with the waste definition data can be found on the consumables/expendables list. Waste that is utilized directly reduces the resupply requirements. Therefore, it is of advantage to understand how the incoming material is consumed or how the usefulness of the incoming material is reduced by use. This information is an indication of the type of process required to refurbish, reconstitute, salvage or otherwise reutilize the waste that results from the consumables/expendables.

Data under the following headings on the consumables/expendables list allow interfacing of the wastes with reclamation processes.

HEADING	TYPICAL CONTENTS	TYPICAL UTILIZATION INTERFACES
HOW CONSUMED	Eaten	None
	Worn	Overhaul
	Saturated	Desaturate
	Failed	Repair
	Filled	Empty
	Clogged	Reverse Flush
	Heated	Cool
	Cooled	Heat
BASIC CONSTITUENTS CONSUMED	Freshness	Launder, Wash
	Life	Overhaul
	Availability	None
	Latent Heat	Boil/Condense
	Chemical Potential	Recharge (electrical)
	Surface Area	Reverse Flush, Solvents
	Sorbancy	Vacuum, Heat

Data under the above headings is supplied in Volume II of the Data Book for each waste and each consumable/expendable item associated with the waste sources analyzed. This constitutes a large body of data that must be judiciously sorted and totalized by the various categories available in order to properly evaluate their impact on the housekeeping task. Tables 3.1-4 and 5 are examples of waste data sorted by areas of origin. Tables 3.1-6 & 7 are examples of waste data sorted by reclamation process.

The analysis of housekeeping requirements using the properly sorted waste data can, when combined with the information contained in the other sections of the data book, result in the following end products.

- Operational waste control procedures by spacecraft area or function. (See Tables 3.1-4 & 5).
- Container types and quantities useful for collection of waste in a given spacecraft area. (See Tables 3.1-4 & 5).
- Waste transport procedures and equipments between collection and disposal/ treatment area (See Tables 3.1-4 & 6).
- Reclamation processes to reduce resupply of expendables (See Tables 3.1-6 & 7).
- Waste materials useable as raw material to manufacture other consumables.
- Processes to convert waste materials to enhance disposal.
- Disposal requirements - rates, routines and equipments (See Tables 3.1-4, 5, 6 & 7)
- Highlighted areas, i.e., those areas that generate large amounts of waste (See Table 3.1-3).

TABLE 3.1-4 WASTE DATA SORT - FOOD PREPARATION AND SERVICING AREA

Area	Data Book Vol. II Ref. Doc. No.	Waste Item	Organic		Plastic		Special	12 Man Rate	12 Man Summary
			Wet	Dry	Sheet	Rigid	Handling	Lb (4) Meal	Lb Yr
Food Storage	1.3.1.1.1	• Maintenance items					(1)	-	10
		• Spoiled Food in packages	x		x			-	10
Kitchen	1.3.2.1.1	Residual Food in packages		x				.05	50
	1.3.2.1.2	" " "	x					.136	136
	1.3.2.2.1	Food packaging			x			2.9	2,900
	1.3.2.2.1	Food spillage	x				(2)	.08	87
	1.3.2.2.1	Wipes						.18	184
	1.3.2.1.1	Water spillage/residuals	x				(2)	1.0	1,007
Dining	1.3.3.2.1	Meal tray				x	(3)	6.6	6,600
		Service tray				x	(3)	1.0	1,065
		Utensils (eat & drink)				x	(3)	5.0	6,000
		Napkins					(3)	.4	392
		Wipes					(3)	.25	270
		Uneaten food	x					2.7	2,780
		Spilled food	x				(2)	.100	100
Snack Bar	-	Assume 10% of Dining Area						1.6	1,600

NOTES:
1. Return to earth for analysis
2. Water/food spill tools required
3. Wash
4. Meal rates taken as yearly rate x 10^{-3} approximately

TABLE 3.1-5. WASTE DATA SORT - AGRICULTURE STUDY AREA
(See Data Book Volume II, Doc. No. 3.3.1.1.1 - 3.1 and 3.4.4.1.1 - 8.1)

Waste Item	Attributes: Organic		Attributes: Plastic		Special Handling (See Notes)	Rate Summary - Lbs. (1)			Remarks
	Wet	Dry	Sheet	Rigid		Daily	Weekly	Total	
• Vermiculite (soil) in zero "G" pots with nutrients added	X				(2), (4)	-	-	5 - 10	Per crop (¼ to ½ cu. ft. soil)
• Agar gel (soil) in zero "G" pots with nutrients added	X				(2), (4)	-	-	4 - 5	Per crop of arabidopsis
• Zero "G" Experiment container - with lights, soil holder and water/nutrient wick systems			X	X	(3)	-	-	10	A lighted tent on a rigid frame
• Partial "G" Experiment container			X	X	(3)	-	-	15	Same as above with centrifuge
• Radioisotopes (C^{14}, H^3)					(4) Radioactive	.002	-	.1 - 1.0	In specimens, CO_2, soil and water vapor
• Temporary Specimen containers				X	(2)	-	1.3	-	During harvest time only
• Chemical spills; auxins, enzymes, nutrients	X	X				.005	-	-	
• Wipes			X		(2)	.125	—	-	
• Plant sheddings	X	X			Mulch?, (4)	.04	-	-	Maximum for leafy plants
• Specimen residues, cut, stained and discards	X	X			Mulch?, (4)	-	.25	-	Peaks at harvest time
• Data sheets			X			-	.03	-	
• Water vapor	X				(4)	.5	-	-	Evaporation, leaks to ECS
• CO_2 leakage					(4)	.1	-	-	For Doc. No. 3.3.1.3.1 only
• Film and wrappings			X			-	.25	-	
• Tools, scalpels, slides, glassware				X	(2)	.5	-	-	

<u>Notes:</u>
1. Rate summary based on single crop size - assuming one field for each crop
2. Wash and sterilize before reusing
3. Reusable for each crop if soil is exchanged and unit hand wiped
4. Radioactive when isotope tracers are used. CO_2 and H_2O vapors could be dangerous to humans

TABLE 3.1-6. WASTE DATA SORT - LAUNDERING PROCESS

Waste Item	Data Book Vol. II Reference Doc. No.	Area of Origin	12 Man Rate Summary - Lbs Daily	Weekly	Yearly	Remarks
Medical Examination Table Covers	1.1.1.1.1	Dispensary	.2	1.3	65.0	Requires auto-claving before laundering
Sick Bay Sheets		Dispensary	-	1.0	50.0	" "
Dental Head Rest Covers	1.1.2.1.1	Dispensary	.03	.2	10.0	" "
Dispensary Gen'l Wipes	1.1.3.1.1	Dispensary	.37	2.6	135.0	" "
		Sub Total	.6	5.1	260.0	
Lounge Furniture Covers (Webbing)	1.2.1.1.1	Bed Rooms	-	-	12.0	1 lb. each - once/year
Crew Clothing	1.2.2.1.1	Bed Rooms	5.0	35.0	1850.0	2-6 day change basis
Bed Linens	1.2.2.2.1	Bed Rooms	-	7.5	393.0	6 day change basis
Blankets and Mattress Covers		Bed Rooms	-	-	40.0	Bi-annual
		Sub Total	5.0	42.5	2295.0	
Kitchen Wipes	1.3.2.2.1	Kitchen	.52	3.6	184.0	
Dining Napkins	1.3.3.2.1	Dining	1.07	7.5	392.0	Based on 100%. Change/Meal-Worst Case Chosen.
Dining Area Wipes	—	Dining	.74	5.2	270.0	
Snack Bar-Wipes/Napkins	—	Snack Bar	.18	1.3	66.0	10% of Dining Area.
		Sub Total	2.51	17.6	912.0	
Shower Towels/Wash Cloth	1.4.2.1.1	Bathroom	4.5	30.0	1550.0	3 Showers/MN/WK
Face Towel	1.4.3.1.1	Bathroom	3.0	21.0	1100.0	1/Man/Day
		Sub Total	7.0	51.0	2650	

TABLE 3.1-7. WASTE SORT FOR DISHWASHING

Waste Item	Area of Origin	12 Man Rate Summary - Lbs. Daily	Yearly	Remarks
Eating Utensils	Dining	6.1	2,710	• Full weight assumed for dishwashing; use 40% for disposable types.
Drinking Utensils	Dining	9.0	3,285	
Meal Tray	Dining	18.0	6,600	
Accessory Tray	Dining	3.0	1,065	• Ref. Data Book, Vol II Doc. Nos. 1.3.2.2.1, 1.3.3.2.1, 1.3.4.2.1
	Sub Total	36.0	13,660	

3.2 PROCESSING FOR UTILIZATION

3.2.1 Introduction

The creation of consumables from the by-products (wastes) of man, the spacecraft systems, and the experiments with the subsequent evaluation of the feasibility and desireability of the proposed utilization process is the purpose of this section.

Types of processes are described on short, one-page summaries. It is the intent of these summaries to aid the system designer by giving him a brief survey of the types of processes that could be applicable, now or in the future, for the utilization of wastes. An attempt has been made to describe the types of materials applicable to a process in the same way that types of wastes were described in Section 3.0 of Volume I and Volume II of the Data Book so that a higher level matching can be effected. Ultimately, a waste item by waste item evaluation must be performed, but only in those cases where the grouped weights, as indicated by the higher level study, represent valuable potential for utilization.

After studying the process summary, the system designer can obtain further information about the concept in the process background section or he can refer directly to the references. Process background is presented in Section 4.0, Volume I of the Data Book, which describes some of the physical characteristics of the candidate system.

The waste utilization/recovery process categories that have been established are: physical separation, electrolysis (water), oxidation, decomposition, reduction (CO_2), compaction, propulsion, and food preparation. The process groupings are indicated in Table 3.2-1.

Physical separation includes multifiltration, centrifugation, distillation, and sorption. These processes result in the physical isolation of mutually contaminating media. They may be used alone or in conjunction with other processes (as in pretreatment of wastes). Oxidation includes incineration and wet oxidation, while decomposition includes thermal (pyrolysis) and bacterial decomposition. These processes (oxidation and decomposition) are discussed in this utilization section, rather than only in the disposal section because of their by-products; minerals in their lowest oxidation state and biomass. Their utility as utilization schemes depends entirely upon the inclusion of regenerative food systems (actual or experimental).

TABLE 3.2-1. PROCESS TABLE

Processing Method	Types of Waste Accommodated	Utilization Potential
Physical Separation		
Filtration	Potentially most fluids, acid alkali, oils, slurries, suspensions, colloids, etc	Closure of water cycle loop, separation and isolation of mutually contaminating media
Centrifugation	Two-phase mixtures of fluids, single phase mixtures of distinctive density fluids	Separation and isolation of mutually contaminating media
Distillation	Easily vocatilized hydrocarbons and contaminated water	Closure of water cycle loop, recovery of contaminated fluids, recovery of dissolved solids
Sorption	Contaminated, low viscosity fluids, water vapor, CO_2, trace contaminants	Purification and recovery of contaminated media
Electrolysis	Waste or excess water	Oxygen and/or hydrogen recovery
Oxidation		
Incineration	Combustible-oxidizable materials, plastics, textiles, paper; as sheet, grains or bulk	Deactivation and reduction of organic wastes
Wet Oxidation	Raw urine and/or feces, urine distillation residue, food wastes	Fertilizers, minerals and raw materials for closing the nutrition loop
Decomposition		
Thermal (Pyrolsis)	Feces, paper, natural textiles, plastics	Hydrocarbon fuels and solvents, fertilizer, minerals for food cycles
Bacterial (Aerobic/Anaerobic)	Organic wastes; textile, paper, fluids, gels, etc in a granular or easily granularized state	1. Human wastes or contaminated debris disposal needing no pretreatment 2. Production of biomass for closing of food loop

TABLE 3.2-1. PROCESS TABLE (Cont'd.)

Processing Method	Types of Waste Accommodated	Utilization Potential
Reduction		
Bosch process	Carbon dioxide	Water for O_2 recovery. Carbon for contaminant control filters
Sabatier process	Carbon dioxide	
Solid Electrolyte process	Carbon dioxide	
Compaction	Packaging wastes, full debris bags, compressable failed components, film, paper, wipes	Creation of usable building blocks for radiation or meteorite shielding
Propulsion	Feces, carbon residue, evaporator wicks, organic filters, food waste, urine	Thrust production
Food Preparation		
Physiochemical	Metabolic wastes, feces, CO_2, urine, atmospheric condensate	Creation of low level foods - carbohydrates
Bioenergetic photosynthesis	CO_2 mineral residue of oxidation	Creation of edible biomass
Bioenergetic non-photosynthesis	Metabolic wastes-feces, CO_2, urine, atmospheric condensate volitile organic compounds	Creation of edible biomass

Reduction processes for the closure of metabolic gas loops are very explicit in their being designed to handle only CO_2. The system flexibility results from the various sources of CO_2 conceivable.

Compaction, as a waste utilization process, can be considered as a method of creating building materials. Propulsion includes the utilization of waste material as a constituent of a fuel mixture or as an exhaustable gas (e.g., high pressure discharge of excess CO_2).

Food preparation methods fall into two general categories: physicochemical or bioenergetic. The physicochemical processes eliminate the danger of some form of crop failure while producing low level foods. The bioenergetic systems can be either photosynethetic or nonphotosynthetic and produce higher level foods.

Common household cleaning equipment can be considered to fall into the realm of utilization processes. For example, a clothing washer and drier processes waste (i.e., dirty clothing) to produce a consumable, clean cloths. Other processes include those for dish and cooking utensils washing and drying; the general cleaning of the man exposed spacecraft surfaces; and any special cleanup process. These utilization processes have been considered (implicity) as special combinations of the general processes described, with the obvious additional physical process of dilution. However, clothes washing has been described in Section 3.3.

3.2.2 Physical Separation

3.2.2.1 Multifiltration

PROCESS NAME: Multifiltration

PROCESS BASIS/PRINCIPLE: Multrifiltration is a method of liquid processing in which waste liquid is filtered through various materials.

MATERIALS TREATED:

1) Potentially most fluids: acids, alkali, oils, colloids, suspensions, scurries, etc.
2) Current usages include, condensate reclamation from EC/LS, and urine water and wash water reclamation

CONSUMABLES REQUIRED: Activated charcoal, bacteria filters, ion exchange resin canisters.

PRODUCTS: Decontaminated fluids, H_2O (pure), contaminated filters

PROCESS DATA:

1) Recovery efficiency, 99 + %
2) Power requirements: minimal -- small pump and conductivity sensor

UTILITY:

1) Closure of the water cycle loop
2) Separation and isolation of contaminants for contaminate reclamation
3) Reclamation of applicable fluids other than water

REFERENCES:

Feindler, K.: Filtering System for Aerospace Water Reclamation; Tech Rep. AMRL-TR-67-151, Aerospace Medical Research Laboratories; December 1967.

Steele, J.A., et al; Water Reclamation Subsystem for Space Stations: NASA CR-66168, 3 July 1963

Tuwiner, S.B.: Research, Design, and Development of an Improved Water Reclamation System for Manned Space Vehicles; Rep. RAI 364 (Contract NAS 1-4373; RAI Research Corp.; April 1966.

3.2.2.2 Centrifugation

PROCESS NAME: Centrifugation

PROCESS BASIS/PRINCIPLE: Dynamically induced inertial forces are utilized to achieve liquid/liquid, liquid/solid, or liquid/gas separation.

MATERIALS TREATED:

1) Two phase: liquid/gas mixtures consisting of water, its vapor, and air liquid/ solid mixtures, e.g. colloids, suspensions and large particle mixtures
2) Single phase: liquid/liquid mixtures of distinctive density fluids

CONSUMABLES REQUIRED: None

PRODUCTS: Separate constituents

PROCESS DATA:

1) Separation efficiency, 99%
2) Power requirements -- small (rotor motor)

UTILITY:

1) Closure of the water cycle loop
2) Preparation of liquid-gas discharges from water using devices prior to purification and reclamation recovery/or reutilization of any fluid that has been contaminated with nonsoluble contaminates of different densities.
3) Removal of excess moisture in the liquid state from air prior to recirculation.
4) In general, the reclamation of mutually contaminating immiscible fluids of different densities.

REFERENCES:

Linzey, T. J.: An Approach to Water Management for Long Duration Manned Space Flight; Aerospace Life Support, Chemical Engineering. Vol 62, No. 63; 1966

3.2.2.3 Distillation

PROCESS NAME: Distillation

PROCESS BASIS/PRINCIPLE: Distillation is the volatilization or evaporation and subsequent condensation of a selected liquid for the purification or concentration of that liquid. The practical distillation systems include various forms of vacuum distillation and humidification, which vary by pressure and carrier gas.

MATERIALS TREATED: Primarily for easily volatilized hydrocarbons and contaminated water.

CONSUMABLES REQUIRED: None.

PRODUCTS: Distiland and distillate, i.e., that which remains and that which has been driven off and recondensed.

PROCESS DATA:

1) Recovery efficiency, 99 + %
2) Power requirements -- moderate due to latent heat requirement of volatilization

UTILITY:

1) Closure of the water cycle loop
2) Recovery of contaminated fluids
3) Recovery of dissolved solids

REFERENCES:

Berninger, J. F.; Charanian, T. R.; and Bambenek, R. A.: Water Reclamation Via Compression Distillation; General American Transportation Corp.; March 1965.

3.2.2.4 Sorption

PROCESS NAME: Sorption

PROCESS BASIS/PRINCIPLE: Sorption is the binding of one substance by another by any mechanism such as absorption (one substance into another), adsorption (one substance onto another), or persorption (a liquid selectively entering a solid matrix, i.e., sponge).

MATERIALS TREATED:

1) Gas mixtures, for the selective removal of particulate contaminants, e.g.
   - desicants -- silica gel for removal of water vapor
   - molecular sieve -- zeolite for removal of CO_2
   - activated charcoal for trace contaminant removal (particle)
   - bacteria filters, etc.
2) Liquids, e.g., filtration of water (covered elsewhere)

CONSUMABLES REQUIRED: Fresh supplies of the particular sorption agent.

PRODUCTS: Exhaust sorption agent and cleaned medium, e.g., contaminated activated charcoal and clean air.

PROCESS DATA:

Power is required to circulate the medium to be processed past, over or through the particular sorption material.

UTILITY:

Purification and recovery of contaminated media.

REFERENCES:

Glueckert, A.J.; Nuccio, P.P.; and Zeff, J.D.: Regenerative Sorbent for Carbon Dioxide Control; Gat-O-Sorb-A, Presented at Aeronautic and Space Engineering and Manufacturing Meeting, S.A.E.; October 1967.

3.2.3 Water Electrolysis

PROCESS NAME: Water Electrolysis

PROCESS BASIS/PRINCIPLE: All water electrolysis concepts carry out the electrochemical process -- $2\ H_2O \rightarrow 2\ H_2 + O_2$

MATERIALS TREATED: Water from water management system and water vapor in cabin air.

CONSUMABLES REQUIRED: Water

PRODUCTS: O_2, H_2

PROCESS DATA: Water electrolysis concepts vary as to method and approach. The categories for variety are: feedwater source, state of water in cell, chemical nature of electrolyte, physical nature of electrolyte, and system configuration. Electrical power is required for the electrolysis as well as for any pumps, humidifiers or fans.

UTILITY: Recovery of contaminated water.

CONSTRAINTS: Water to be processed must be relatively free of electrolytes and impurities that could alter the process or products.

REFERENCES:

"A Flight Prototype Water Electrolysis Unit" - Glanfield, Edward J.; Miller, Ralph A.; and Rudek, Fred P. - Aerospace Life Support, Leonard Elihan, ed., Am. Inst. of Chem. Engrs. (New York, 1966 pp. 24-28.

"Water - Electrolysis - Prospect for the Future" - Wydeven, T.; and Johnson, R.W. - Paper presented at Annual Aviation and Space Conference, ASME (Beverly Hills, California), June 1968.

3.2.4 Oxidation

3.2.4.1 Incineration

PROCESS NAME: Incineration

PROCESS BASIS/PRINCIPLE: Incineration is the complete oxidation of wastes using either pure oxygen or oxygen diluted with an inert gas such as nitrogen.

MATERIALS TREATED: Combustible (oxidizable materials) such as:

1) Plastics, textiles, paper (as sheets, bulk or grains)
2) Pathogenic, active or inert (raw urine, feces, foodwaste, urine distillation residue)

CONSUMABLES REQUIRED: O_2, N_2 (diluent gas)

PRODUCTS: A dry heavy molecule powder

PROCESS DATA:

1) Nominal $T = 1000°F$, nominal $P < 1$ psi
2) Reduction of material is approximately 97 to 99%

UTILITY:

1) Deactivation of complex organic wastes (including biological)
2) Waste reduction and disposal
3) Raw material for closing the nutrition loop
4) Fertilizer and minerals production

REFERENCES:

Anon: "Waste Disposal for Aerospace Missions," Tech. documentary rep. AMRL-TDR-64-3 (Contract AF33(616)-8203 for WPAFB), MRD, January 1968.

3.2.4.2 Wet Oxidation (Zimmerman Process)

PROCESS NAME: Wet Oxidation

PROCESS BASIS/PRINCIPLE: Elevated temperature and pressure oxidation of aqueous slurries or solutions of organic materials.

MATERIALS TREATED:

1) Raw urine and/or feces
2) Urine distillation residue
3) Cellulose, sucrose, etc.
4) Proteins, amino acids

CONSUMABLES REQUIRED: O_2

PRODUCTS: CO_2, H_2O, N_2, NH_4 salts, CH_3 COOH, white precipetent in aqueous phase

PROCESS DATA:

1) Nominal T = 500°F, nominal P = 2000 psi
2) Thermal requirements, ca. 150 BTU/lb.
3) Conversion efficiency, 95% (organic)

UTILITY:

1) Deactivation of complex organic wastes (including biological)
2) Closure of carbon balance (in conjunction with CO_2 reduction)
3) Generation of plant nutrition media through lower level (partial) oxidation

REFERENCES:

"Investigation of the Feasibility of Wet Oxidation for Spacecraft Waste Treatment" - R. B. Wheaton et al. NASA CR66450, 1967.

"Wet Oxidation for Space Waste Management" - J. Konikoff and T. Slawecki, SAE Paper 689714, October 1968.

"The Problems of the Possibility of the Mineralization of Water - Fecal Mixtures by the Method of Wet Burning" - A. L. Agre et al. NASA TT 66-34698, October 1966.

3.2.5 CO_2 Reduction

3.2.5.1 Bosch Process

PROCESS NAME: Bosch System

PROCESS BASIS/PRINCIPLE: The Bosch system uses a single carbon dioxide reduction reactor operating at 1200°F. It is a hydrogenation process. Within the reactor, water vapor and carbon are formed on a steel wool catalyst by the following reaction: $CO_2 + 2H_2 \rightleftarrows C + 2H_2O$

MATERIALS TREATED: CO_2

CONSUMABLES: H_2 and catalyst cartridges

PRODUCTS: H_2O

PROCESS DATA: Carbon is removed from the system by periodic replacement of the carbon-loaded catalyst cartridge. The reaction is exothermic and the heat must be rejected to a consenser coolant.

UTILITY: Closing of the H_2O loop, removal and reduction on CO_2

REFERENCES:

Martin, Rex B.: Carbon Dioxide Control for Manned Spacecraft. Selected Papers on Environmental and Attitude Control of Manned Spacecraft, NASA TMX-1325, December 1966.

Anon.: Research and Development Programs for a Combined Carbon Dioxide Removal and Reduction System. NASA CR-66519, November 1967.

3.2.5.2 Sabatier Process

PROCESS NAME: Sabatier (Methane Cracking)

PROCESS BASIS/PRINCIPLE: Sabatier-methane cracking is a hydrogenation process. CO_2 is hydrogenated to form water vapor and methane by the following reaction:

$CO_2 + 4H_2 \rightleftarrows CH_4 + 2H_2O$

The methane can be decomposed by cracking in an additional reactor by the reaction

$CH_4 \rightleftarrows C + 2H_2$

MATERIALS TREATED:

CO_2 (by Sabatier); CH_4 (by cracking)

CONSUMABLES: H_2 and carbon loaded catalyst cartridges

PRODUCTS: CH_4 and H_2O (by Sabatier) ; C and H_2 (by cracking)

PROCESS DATA: Combined system -- carbon dioxide (from concentration) and hydrogen (from electrolysis) are combined with recycle stream from the methane cracking reactor (which produces H_2). This mixture enters the hydrogenation reactor where an isothermal reaction occurs at about 500°F. The resultant methane is partially (60 → 85%) decomposed at 1800°F in the associated cracking reactor.

UTILITY:

1) Remove and decompose CO_2
2) Make up for metabolic water losses

REFERENCES:

Anon.: Research and Development Program for a Combined Carbon Dioxide Removal and Reduction System NASA CR-66519, November 1967.

Clifford, J. E., et al.: Investigation of an Integrated Carbon Dioxide Reduction and Water Electrolysis System. Tech rep. AMRL-TDR-66-186, Aerospace Medical Research Laboratories, April 1967.

3.2.5.3 Solid Electrolyte Process

PROCESS NAME: Solid Electrolyte Process

PROCESS BASIS/PRINCIPLE: The solid electrolyte system recovers oxygen from carbon dioxide in a single reaction step at elevated temperatures.

$$CO_2 + H_2O \rightarrow CO + O_2 + H_2$$

These reactions are assisted by the electrochemical transfer of oxygen ions from a cathode through a ceramic electrolyte to an anode where oxygen gas is formed. A second step is required for carbon deposition

$$2CO \rightarrow C + CO_2$$

MATERIALS TREATED: CO_2 (CO in second step)

CONSUMABLES: H_2O

PRODUCTS: O_2, H_2, C

PROCESS DATA: Inlet CO_2 (mixing with the circulating reaction gas stream) is humidified and then heated to 1800°F where O_2, CO, and H_2 are formed. The second reaction is used to deposit out the carbon (disproportionation reactor). Carbon is deposited on the catalyst and carbon dioxide is recycled back to the solid electrolyte reactor.

UTILITY:

1) Decomposition of CO_2 and CO
2) Production of O_2 and H_2

REFERENCES:

Chandler, H. W.; and Pollara, F. Z.: Oxygen Regeneration in a Solid Electrolyte System. Aerospace Life Support, Leonard Elikan, ed., Am. Inst. of Chem. Engrs. (New York), 1966, pp. 38-42.

Elikan, Leonard; Archer, D. H.; and Zakradnik, R. L.: Oxygen Reductionin Solid Electrolyte Batteries - Fundamental Considerations. Aerospace Life Support, Leonard Elihan, ed., Am. Inst. of Chem. Engrs. (New York) 1966, 11.29-37.

3.2.6 Decomposition

3.2.6.1 Thermal (Pyrolysis)

PROCESS NAME: Thermal (Pyrolysis)

PROCESS BASIS/PRINCIPLE: High temperatures (with the absence of oxidizing agents) lead to chemical decomposition and volitization of organic compounds.

MATERIALS TREATED: Organic wastes; textile, paper, oils, colloids (any form)

CONSUMABLES REQUIRED: None

PRODUCTS: A residue approximately 12% (by weight) of the original waste remains after the pyrolysis

PROCESS DATA: Temperature approximately 1200°F. Water content can be driven off at 250°F for 30 minutes prior to the pyrolysis.

UTILITY:

1) Can be used for human wastes and other contaminated debris, i.e., bandages, if an adequate sterilization cycle is provided prior to pyrolysis.
2) Raw materials for closing the nutrition loop; fertilizers, minerals.
3) Potential usage of residues for hydrocarbon fuels and solvents.

REFERENCES:

"Waste Disposal for Aerospace Missions" - Anon. - Tech. Documentary Rep. AMRL TDR-64-3 (Contract AF33(616)-8203 for WPAFB), MRD, January 1968.

3.2.6.2 Biodegradation

PROCESS NAME: Anerobic and Aerobic Biodegradation

PROCESS BASIS/PRINCIPLE: The biodegradation concept is a biological process in which organic waste compounds are used up by biota, either in the absence (anerobic biota) or presence (aerobic biota) of free oxygen.

MATERIALS TREATED: Organic wastes; textile, paper, fluids, gels, etc., in a granular or easily granularized state.

CONSUMABLES: Anerobic, none; Aerobic, O_2

PRODUCTS: Anerobic -H_2S, CO, pyrimidines; Aerobic -CO_2

PROCESS DATA: The anerobic (waste digestion) process utilizes oxygen derived from compounds in the waste products, is relatively slow, and results in the above noxious gases. The main digestor gases are CH_4 and CO_2 and pathogens tend to survive in this type of environment. The aerobic method utilizes an external oxygen supply, is rapid, and results in nonnoxious (CO_2) end products that do not support pathogens. Two principal aerobic processes are available: the activated sludge and the trickling filter process.

UTILITY:

1) Can be used for human wastes and contaminated organic debris without the need of pretreatment, i.e., sterilization or dehydration.

2) Production of raw materials and/or biomass for use in closing of food loops.

REFERENCES:

Anon: (AKSS) "Trade-off Study and Conceptual Designs of Regenerative Advanced Integrated Life Support Systems". Task 2 Report NASA Contract No. NAS-1-7905 by Hamilton Standard, December 2, 1968.

3.2.7 Compaction

PROCESS NAME: Compaction

PROCESS BASIS/PRINCIPLE: Suitable debris are compressed to approximately 25 to 30% of their initial volume in a hydraulic cylinder.

MATERIALS TREATED: Packaging wastes, full debris bags, compressible failed components and all organic sheet materials, e.g., film, paper, wipes

COMSUMABLES:

1) Power
2) Storage containers for compacted debris
3) Binding agent

PRODUCTS: High density blocks of compacted debris

PROCESS DATA: The compaction unit provides high-density compression of the debris by utilizing a pressure plate controlled by a pressure system (hydraulic, pneumatic, screw jack, etc.) that is capable of exerting large forces. The pressure plate forces the bags and liners against the lower end of the compactor cylinder. Hardness sensors and self-limiting controls are incorporated into the pressure plate; these controls and sensors determine the optimum degree of compaction for a particular accumulation of trash and protect the pressure-plate driving mechanism from excessive stresses. Binding agents can be added to the compressed debris to stabilize the geometry of the resulting block, inhibit bacteria growth, and provide uniform surfaces.

UTILITY:

1) Inert waste disposal
2) Creation of usable building blocks for a radiation shelter, meteorite shielding, or thermal barriers.

REFERENCES:

Space Station Preliminary Design, Vol. 1, Book 3. McDonnell Douglas Astronautics Co. Contract NAS8-25140, July 1970.

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3.2.8 Propulsion Applications

PROCESS NAME: Rocket Propulsion Materials Generation

PROCESS BASIS/PRINCIPLE: Waste materials, when combined with powdered aluminum and ammonium nitrate, produce a safe, thixotropic monopropellant having a normal theoretical specific impulse of approximately 230 to 240 lbs-sec/lbs.

MATERIALS TREATED: Feces, carbon residue, evaporator wicks, organic filters, food wrappers, food waste, and liquid wastes (urine or surplus from fuel cells).

CONSUMABLES: Powdered aluminum and ammonium nitrate

PRODUCTS: Thrust

PROCESS DATA: The weight of an integrated system will be lighter than a spacecraft system in which the waste management and propulsion subsystems are separate entities. Weight reductions stem from smaller propellant storage tanks and a high, effective specific impulse for the waste propulsion system, i.e., a significant fraction (25 to 45 percent by weight) of the combusted propellant is free as spacecraft waste and, therefore, is not charged against the propulsion system weight.

High-temperature oxidation (combustion) of the waste material is expected to completely exclude any possibility of living organisms in the exhaust products ejected from the spacecraft. The performance of the integrated waste management/rocket propulsion system is very insensitive to variations in amount of available waste. Propellant formulations can easily be modified to make maximum use of the available waste.

UTILITY: This concept presents a potentially effective and efficient means of disposing of spacecraft wastes, including feces, while providing a moderate amount of thrust for station keeping.

REFERENCES:

Feasibility Investigation of an Integrated Waste Management/Rocket Propulsion System, C. D. Good, E. W. Schmidt, J. E. Mars, et al. NASA-6750 by Rocket Research Corporation, January 1969.

3.2.9 Food Preparation

3.2.9.1 Physicochemical

PROCESS NAME: Physicochemical Synthesis of Monosaccharides from the Product of Human Vital Functions.

PROCESS BASIS/PRINCIPLE: Carbohydrates (monosaccharides) can be synthesized by the condensation of formaldehyde, which can be produced from the products of body functions.

MATERIALS TREATED: Feces, CO_2, urine, atmospheric condensate, and other volatile organic compounds .

CONSUMABLES: Power (electrical)

PRODUCTS: Carbohydrates (formic acid ± pigments are also produced)

PROCESS DATA: The products of vital functions are placed in a mineralizer where, at a temperature of 150 to 200°F, pyrolysis occurs with the release of organic matter in a gas phase. The organic compounds forming during pyrolysis are fed by a blower into a catalytic reactor where the volatile substance are oxidized to CO_2, H_2O, N_2, SO_2, and NO and are absorbed by sulfur oxides with a zinc oxide catalyst. As a result of the exothermic character of the reaction, the temperature in the reactor increases to 500 to 600°F. Accordingly, the catalytic furnace must be heated only during the initial period, after which the reactor operates without external heating. The condensation of water vapor occurs in the condenser and, after purification, the forming water can be drawn from the collector for drinking. A mixture of gases is fed into a silica gel cartridge for moisture absorption and then into an absorber-reactor filled with zeolites and nickel hydrogenant catalyst. The carbon dioxide exhaled by man is also fed into the absorber. After completion of mineralization, hydrogen is fed into the absorber-reactor for hydrogenating the carbon dioxide and monoxide and the desorbed nitrogen oxides. The forming CH_4, water vapor, and NH_3 pass through the condenser desiccator for absorbing NH_3 and H_2O. The remaining CH_4 is fed into the oxidation reactor where formaldehyde is formed in a BaO_2. Ag_2O catalyst. This formaldehyde is bubbled through a solution containing $Ca(OH)_2$ with the formation of monosaccharides. Because only part of the methane is oxidized during one pass through the catalyst chamber, the system has provision for the circulation of the unreacted mixture by means of a blower. The mixture of carbohydrates passes through a filter for purifying it from the catalyst, formic acid, and pigments. The purified carbohydrates are fed into the collector. Traces of organic compounds that did not enter into reaction are oxidized in the catalytic reactor.

UTILITY: Production of food and consumption of human wastes.

REFERENCES:

"Physicochemical Synthesis of Monosaccharides from the Products of Human Vital Functions." Yu. Ye. Sinyak UDC 547.455.07:629.78

3.2.9.2 Photosynthetic

PROCESS NAME: Bioenergetic Photosynthesis of Food

PROCESS BASIS/PRINCIPLE: During photosynthesis, quantum energy E_{hr} of visible radiation from the sun converts chlorophyl molecules and other molecular structures of plant chloroplasis, which are a special apparatus for receiving solar energy, to a higher excitation level with energy E_1^4. As this occurs in an idealized photosynthesis process, six gram molecules of H_2O and six gram molecules of CO_2, passing through a chain of intermediate reactions E_1 E_2 E_3 etc., form a single molecule of saccharoglucose $C_6(H_2O)_6$, i.e., a carbohydrate molecule is formed from carbon C and water H_2O (also liberating O_2). Simplified (as simplified reverse of respiration):

$$6CO_2 + 6H_2O \quad C_6(H_2O)_6 + 6O_2$$

MATERIALS TREATED: CO_2

CONSUMABLES: Light energy in visible range and H_2O

PRODUCTS: O_2, $C_6(H_2O)_6$-- Carbohydrate, and biomass

PROCESS DATA: Photosynthesis must take place in an illuminated environment. Organisms chosen to perform the reaction must be maintained within their specific environmental requirements.

UTILITY: Production of food and O_2 and the consumation of CO_2 (waste gas)

REFERENCES:

"Life Support of Spacecraft Crews" G.I. Voronin, et al - USSR Accession Number N68-32901, 12 August 1968.

3.2.9.3 Nonphotosynthetic

PROCESS NAME: Bioenergetic Nonphotosynthetic Production of Food

PROCESS BASIS/PRINCIPLE: Hydrogen - fixing hydrogenomonas bacterium, which grows in the dark, produces carbohydrates by the overall reaction:

$$6H_2 + CO_2 + 2O_2 \ (CH_2O + 5H_2O)$$

MATERIALS TREATED: Metabolic wastes and CO_2

CONSUMABLES: H_2, O_2, N_2, and salts

PRODUCTS: Protein

PROCESS DATA: The bacterium, hydrogenomonas eutrophia, when grown in the autotrophic mode requires salts, hydrogen, oxygen and a nitrogen source such as urea or ammonia. It is estimated that 12 liters of culture (6.1 gm/1) is sufficient to convert the entire inventory of one man's CO_2 output to cell mass.

These bacteria, which can utilize metabolic wastes for autotropic growth, have been shown to contain high quality protein. If an apparatus could be designed to produce this material during space flight, an even greater reduction in the amount of food that would otherwise have to be carried along would result. It is unlikely that hydrogenomonas can be made a major component of the diet as it contains too large an amount of nucleic acids to be tolerated by humans. It could, however, serve as a very useful food supplement.

UTILITY: Production of food from wastes and utilization of CO_2 and excess N_2.

REFERENCES:

"Current Research on Regenerative Food Systems"
Shapira, Mandel, Quattrone, and Bell
Ames Research Center, NASA N68-34494.

3.3 WASTE DISPOSAL AND PRETREATMENT FOR DISPOSAL

3.3.1 Introduction

This section summarizes the various waste pretreatment and disposal concepts studied during the course of the contract. The reader is referred to Volume I of the Data Book for a more detailed treatment of any given concept.

The areas of microbial control and compaction are intimately associated with disposal. In addition to deactivating waste for safe storage prior to disposal, microbial control also sanitizes or sterilizes certain waste, thereby conditioning it for reuse and eliminating the necessity for its disposal.

A number of possible methods exist for ultimately disposing of the waste materials produced. Some wastes can simply be ejected from the space station as gases, vapors, or solids. Some can be suitably packaged, stored, and returned to earth by shuttle. In some cases, they can be separated from a returning shuttle to burn upon entering the atmosphere. A separate deorbit vehicle can be used to achieve the same results. For some types of wastes, none of these methods are acceptable. Some hazardous wastes have to be transferred to high earth orbits to provide an orbit life long enough for radiation intensities to decay to safe levels, while still retaining the option of recovery. Also, it will be necessary to send certain hazardous wastes into solar orbits.

There is growing concern about a debris atmosphere surrounding manned spacecraft. The effluents which contribute to the contamination cloud around a space station are atmospheric leakage and dump, propellant exhaust, and liquid and condensable vapor dump. The long term effect of a tenuous atmosphere surrounding the station will be a gradual, but cumulative, surface depositing process. Thermal control coatings, spacecraft windows, optical surfaces and solar arrays could all be adversely affected. It may not be wise to select a disposal system that involves the intentional venting of large quantities of condensable vapors.

Many of the concepts presented for deactivating or sterilizing waste utilize a vacuum source to purge chambers or to provide low temperature drying or evaporative cooling. Condensers should be utilized to restrict overboard venting to noncondensable gases. Overboard vent lines could be eliminated entirely by providing an onboard vacuum source. In the disposal section, the vacuum decomposition of waste is presented as a disposal concept since several sources have suggested this approach. This method of disposal involves venting large quantities of condensable vapors overboard. These vapors include oils, tars, and water and would contribute heavily to the external debris atmosphere. The deleterious effects of condensable vapor venting may in itself eliminate disposal alternates designed to vent such vapors overboard.

The intent here is not to dictate a particular disposal method, but rather to present qualitative and quantitative data that will assist in arriving at such a decision.

3.3.2 Microbial Control for the General Treatment of Contaminated Waste, Both for Reuse and Disposal

The bulk of waste generated in a space station will require some degree of microbial control prior to its disposal. The basic reasons for controlling the bacterial content of the waste are as follows:

1) To prevent transmission of disease and infection
2) To prevent decomposition (deterioration) and spoilage
3) To prevent contamination

All of the methods used for inhibiting or destroying microorganisms are based on subjecting them to an injurious chemical substance or to an unfavorable physical condition. Some of the methods used are bacteriocidal in nature, the intent being to destroy the bacteria. Other methods are essentially bacteriostatic and act to prevent the growth and activity of the bacteria.

3.3.2.1 Desiccation

Desiccation or dehydration of the microbial cell and its environment imposes a static condition upon the microorganism. Moisture is required for their normal growth processes; deprivation of water halts these processes. The required degree of dryness to deactivate a given material is a function of the salt content of the residue. The fecal drying chambers to be used in the Orbital Workshop waste management system are designed to dry fecal material to a maximum liquid/solid ratio of .2. Indications are that urine residue also will be sufficiently deactive if dried to this degree. Food waste will have to be dried to a greater degree to prevent putrefaction or decomposition. Dried packaged foods normally have a moisture content of about 3%. Testing is required to determine the maximum moisture content for stored food waste. To maintain the deactive state, the wastes must be kept dry during their storage period prior to disposal.

3.3.2.1.1 Vacuum Desiccation System Designed for Orbital Workshop

The waste management system chosen for the Orbital Workshop program uses vacuum drying for the preservation of fecal waste. In this system, fecal material is collected in individual teflon bags, utilizing a blower-induced air flow to create the necessary drag required for zero-gravity collection. One side of the fecal collection bag contains a Zitex H662-123 ® filter that acts to retain bacteria within the bag. This is a selectively permeable teflon filter that is permeable to water vapor and impermeable to fluids. The fecal collection bag is shown in Figure 3.3-1.

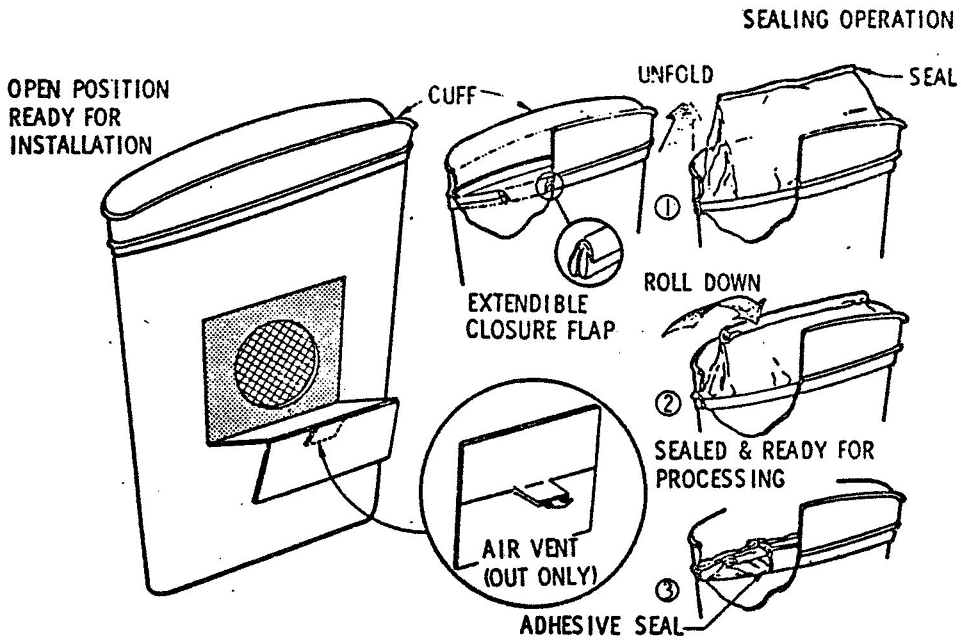


Figure 3.3-1 Fecal Collection/Desiccation Bag Designed for Orbital Workshop

After collection, the bag opening is sealed, and the bag is manually transported to a vacuum drying chamber. When the chamber door is opened, linkage connected to the door retracts a spring-loaded pressure plate within the unit. The bag is inserted, filter side up, and the door is closed. A timer is indexed to the required drying interval (about 8 hours), and the vacuum valve handle is then rotated to exhaust the chamber to vacuum. The base of the chamber is electrically heated to supply the latent heat required for vaporization. The spring-loaded pressure plate holds the bag against the heated surface during the drying cycle and provides a degree of compaction during the later stages of drying. The pressure plate also actuates a throttling valve on the chamber exhaust line, as a function of the guage pressure within the bag. The intent is to protect the bag filter. A pair of vacuum desiccation chambers are shown in Figure 3.3-2.

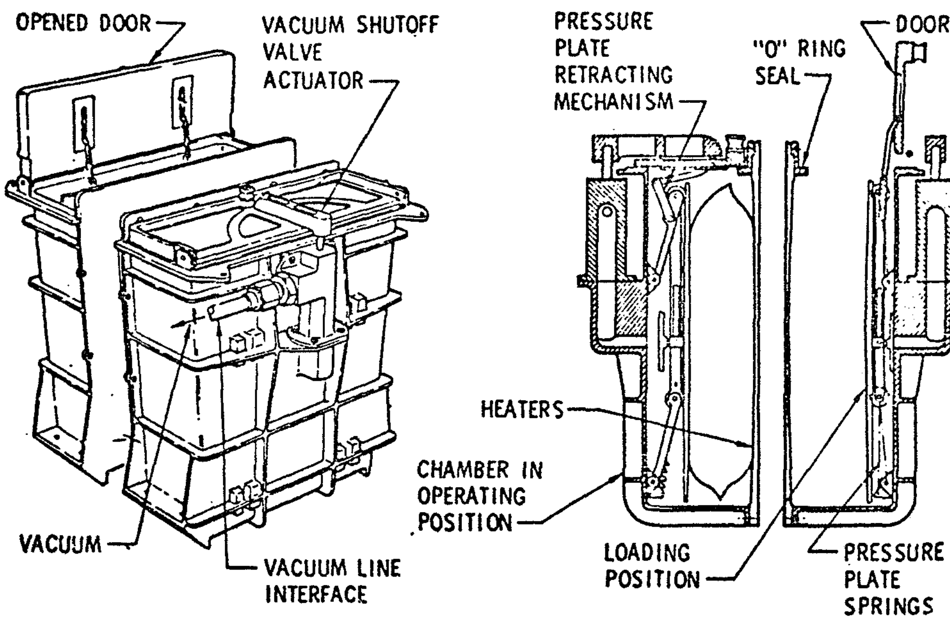


Figure 3.3-2 Vacuum Desiccator Chamber Designed for Orbital Workshop

3.3.2.1.2 Conceptual Design for a Static Food Waste Desiccator

One large source of moist, biodegradeable waste is generated in the food preparation area. It is estimated that there will be approximately .4 lb per man day of food waste generated with an average moisture content of 50% by weight. One method of deactivating this waste is to desiccate it. A conceptual design for a static food waste dessicator appears in Figure 3.3-3. A bellowed collection/compaction container is

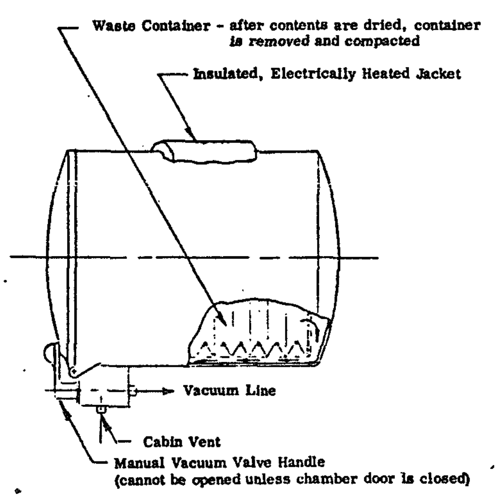


Figure 3.3-3 Static Food Waste Desiccator

used in conjunction with a blower-induced air flow to collect the food waste. After collection, the bag opening is sealed and manually placed in the static food waste desiccator. The door is closed, and the vacuum valve handle is rotated to exhaust the chamber. The latent heat of vaporization is supplied by an insulated, electrically heated jacket, which surrounds the chamber. A selectively permeable filter is incorporated into one end of the bag to permit the passage of water vapor while retaining liquid and solid material. When the drying cycle is completed, the vacuum valve handle is rotated to vent the chamber to the cabin. The bag is removed and then compacted as discussed in Section 3.3.4.

3.3.2.1.3 Conceptual Design for a Rotary Food Waste Desiccator

In the larger space station or base, a considerable quantity of waste will be generated in the food preparation areas. A design for a rotary food waste desiccator, capable of drying and compacting a considerable quantity of food waste before requiring emptying, is illustrated in Figure 3.3-4. In this concept, the food waste is shredded

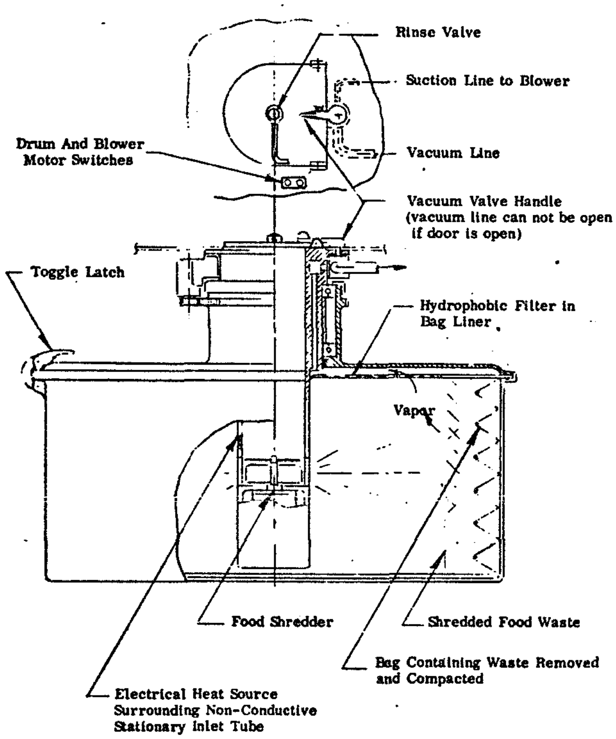


Figure 3.3-4 Rotary Food Waste Shredder/Desiccator

and centrifugally compacted while being dried. A blower-induced air current is used to direct the waste into the shredding mechanism, from which it is centrifugally propelled to the outer wall of the rotating drum. A flexible, bellowed bag is incorporated in the design to facilitate removal of and to provide containment for the dried waste. A rinse is incorporated into the cycle to introduce a small quantity of water to cleanse the mechanism. Space vacuum is utilized to provide low temperature drying, the heat of vaporization being supplied by the centrally located heat source.

3.3.2.1.4 Conceptual Design for a Rotary Slurry Waste Desiccator

The larger 50 to 100 man space station or base will generate large quantities of fecal, urine, and food waste. It is reasonable to assume that a plumbing system will evolve for transporting slurries of such waste to a central processing and disposal section. One design for a rotary slurry waste desiccator is depicted in Figure 3.3-5. In this

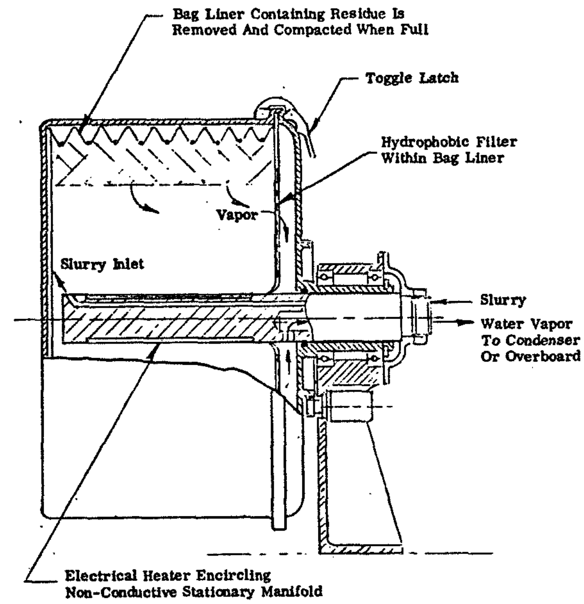


Figure 3.3-5 Rotary Slurry Waste Desiccator

design, the waste slurry enters the rotary desiccator through a statically mounted, centrally located manifold. The slurry is centrifugally held at the outer annulus of the rotating drum while being dried. The heat of vaporization is supplied radiantly by an electrical heat source imbedded within the centrally located manifold. The manifold is constructed of a ceramic material to prevent conductive heat loss to the supporting structure. Vapor leaves the unit through a passageway within the manifold to either a water recovery system or an overboard vent. A flexible bellowed bag is used to contain and to facilitate removal of the dried residue.

3.3.2.1.5 Conceptual Design for a Static Condenser for Use with Desiccators

If desiccation is used as the agent for deactivating the waste, the resultant water vapor can be condensed for reuse.

Gravity is not the only possible motive force for fluid motion. Forces associated with liquid surface tension are another possibility. If a free liquid surface experiences a temperature gradient, a surface tension gradient will result. Along the surface, the liquid will flow from the region of low surface tension to one of high surface tension. This will be from hot regions to colder regions because surface tension generally decreases with an increase of temperature. Fluid flow caused by surface tension gradients is called the "Marangoni" effect. In addition to temperature gradients, surface tension forces will drive liquid drops to the corner of shallow angled cones or wedges, which affords a minimum energy configuration. The proper use of hydrophilic and hydrophobic surfaces enhances this driving force. One concept for a static condenser utilizing such motive forces appears in Figure 3.3-6.

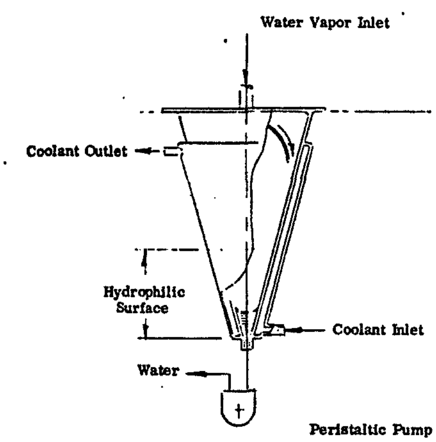


Figure 3.3-6 Static Condenser

3.3.2.1.6 Conceptual Design for a Rotary Condenser for Use with Desiccators

Centrifugal force, as a motive force in zero-gravity, has several distinct advantages. Designs utilizing centrifugal force are not dependent upon temperature gradients or surface properties and can be thoroughly tested in a 1G environment. Conventional analysis can be applied to such designs with predictable results. One design for a rotary condenser appears in Figure 3.3-7. For illustrative purposes, a dual unit is depicted, consisting of a rotary slurry waste desiccator and a rotary, wiped film condenser. The unit has the potential of providing potable water. The regulated pressure within the unit is maintained below atmospheric, providing a driving force for the urine or food waste slurry entering the evaporator. An inlet solenoid valve, in conjunction with a liquid sensor, is used to prevent cabin air from entering the

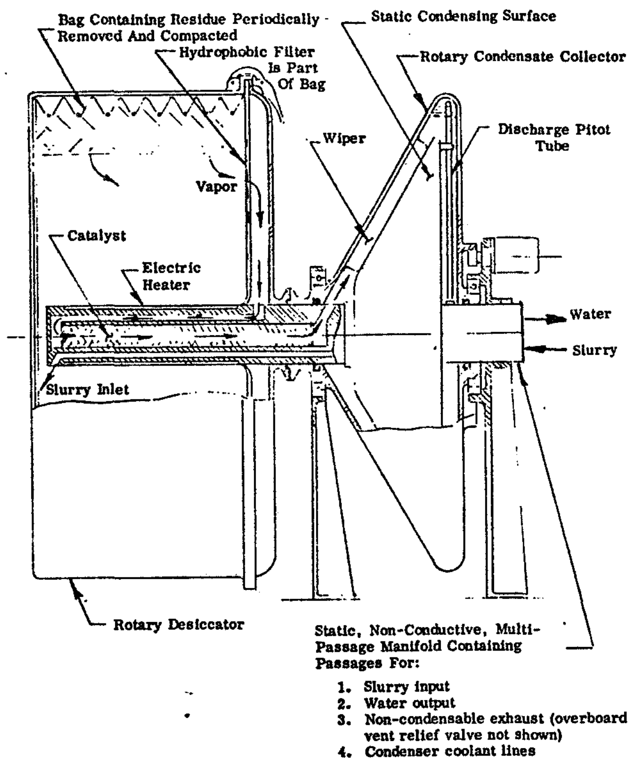


Figure 3.3-7 Rotary Slurry Waste Desiccator with Wiped Film Condenser (Water Recovery Unit)

unit after the slurry is introduced. The evaporator and condenser are thermally insulated from one another. The evaporator section contains a teflon bag liner to permit easy removal of the dried urine or food waste residue. Heat of vaporization is provided by a statically mounted, centrally located, electrical heat source. Water vapor exits the evaporator through the central heat source, where impurities are oxidized in the presence of a catalyst. Water vapor is condensed on a statically mounted, conically shaped, cooled surface within the condenser section. As condensate forms, it is wiped from the condenser surface and centrifugally conveyed to a sump within the outer rotating shell. A static pitot tube within the sump is used to continually discharge condensate. Noncondensable vapors are automatically vented overboard through a pressure relief valve.

3.3.2.2 Refrigeration

Maintaining biodegradable waste at 34 to 38°F reduces the metabolic activity of microorganisms present to the extent that they can be considered dormant. Waste maintained at these temperatures can be stored indefinitely without significant deterioration.

Waste material that requires deactivation inherently has a free moisture content sufficient to cool itself by evaporation and/or sublimation. Because space vacuum is readily available, this approach to deactivating waste is very attractive. Vacuum refrigeration or freezing, in addition to being the most dependable method for deactivating waste, does not require an interface with either the vehicle's electrical power system or coolant loop. A conceptual design for a waste storage refrigerator, designed to refrigerate or freeze waste by the cooling effect of evaporation or sublimation, is shown in Figure 3.3-8. A pressure regulator in the vacuum line provides a means of temperature control.

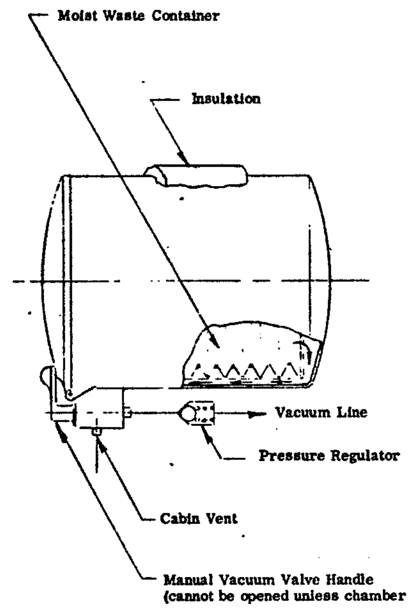


Figure 3.3-8 Moist Waste Storage - Refrigeration Concept

3.3.2.3 Radiation

All living organisms can be sterilized with radiation. Both high energy electrons and gamma rays are being used terrestrially for sterilization. Gamma radiations are emitted from certain radio isotopes such as Cobalt 60 and Cesium 137. A typical sterilizing dose is 2.5 megarads, which includes an adequate safety factor for most conditions. At this dosage, the degree of sterility attained in material containing the most radiation resistant microorganisms normally encountered is at least as good as that obtained by autoclaving at 250°F for 20 minutes. This type radiation does not induce radioactivity in the processed material; the misapprehension on this point comes from confusion with neutron irradiation, which does produce radioactivity.

The use of radiation sterilization techniques in the larger space station are worthy of consideration. Figure 3.3-9 presents a concept for sterilizing liquids. This type of

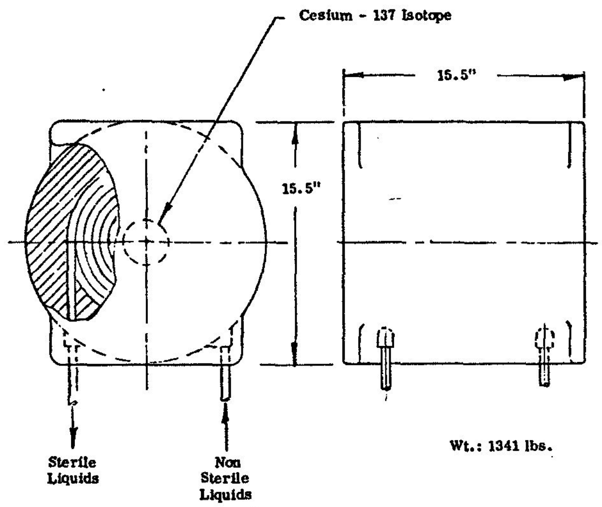


Figure 3.3-9 Gamma Ray Sterilizer for Liquids (26.4 lbs/hr)

sterilizer could be used to impart a high degree of sterility to water emerging from water recovery units and to provide a capability for sterilizing an inadvertently contaminated water supply. A sterilizing dose of 2.5 Mrad is equivalent to 6 calories/gm. The resulting rise in temperature of water given such a dose is 6°C.

3.3.2.4 Germicidal Detergent Formulations

Germicidal detergent formulations hold prominent positions as antimicrobial agents. These are surface tension depressants that are used primarily for sanitizing surfaces. Aside from their germicidal activity, a real value lies in their ability to facilitate the mechanical removal of microorganisms from the contaminated surface. There are many patented detergent compositions. Numerous bacteriostats have been proposed to the detergent industry for sanitizing fabrics, which provide a residual, nonirrating finish to the fabric (i.e., Irgasan ®). An evaluation of detergent formulations for a specific usage is, in itself, a broad and complex field. Detergent formulations incorporating the desirable features of material compatibility, nonirritation, penetration, spreading, residual antimicrobial finish, solubilization, emulsification, low sud formation, and germicidal activity can be prepared for both general and specific usage.

Soiled clothing, linens, and toweling represent a major portion of the waste generated, currently being estimated at .58 lbs/man/day. This material will either have to be sanitized for reuse or disposed of. As the space missions increase in size and duration, the concept of a space laundry system becomes more attractive. Several zero-gravity space laundry concepts are presented in the following paragraphs.

3.3.2.4.1 Conceptual Design for a Manual Clothes Washing Device

The basic reasons for considering automation for cleansing clothing are convenience and crew time criticality. Because scheduled exercise periods are anticipated, a manually operated washing device would appear worthy of consideration. A small, self-contained, manually operated washing device for each crewman is envisioned. This would avoid problems of cross-contamination. The unit would consist of two flexible bags: one containing the items to be washed, and the other, the germicidal cleansing formulation. The two bags would be interconnected with a central section containing two passageways. Washing solution would exit the washing bag through one passageway and return filtered through the other passageway. The manual washing action would be that of squeezing the cleansing solution back and forth between the bags, the solution being filtered each time it re-enters the washing bag. A conceptual design for this device appears in Figure 3.3-10.

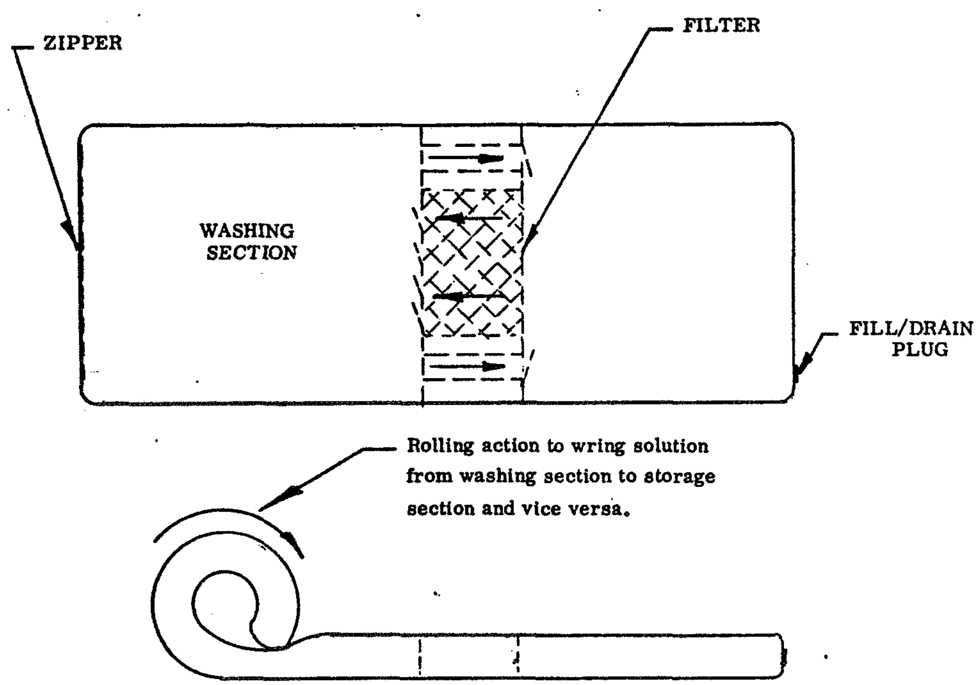


Figure 3.3-10 Manual Clothes Washing Device

3.3.2.4.2 Conceptual Design for a Diaphragm Actuated Washer/Dryer

The conventional method of cleaning fabrics is to apply agitation in conjunction with immersion in a washing solution. One essential factor is that the washing solution be forced into the fibers of the material. One design for an automated zero-gravity washer/dryer unit is shown in Figure 3.3-11. This unit provides washing action by alternately soaking and squeezing the clothing semidry. The washing solution is pumped from one chamber to the other by alternately compressing butyl rubber diaphragms, utilizing a source of compressed oxygen that is introduced through an automatic reversing valve. At the end of the wash and rinse cycles, both diaphragms are pressurized to expel the liquid from the unit to the wash water recovery system. The unit is electrically heated to provide a drying cycle.

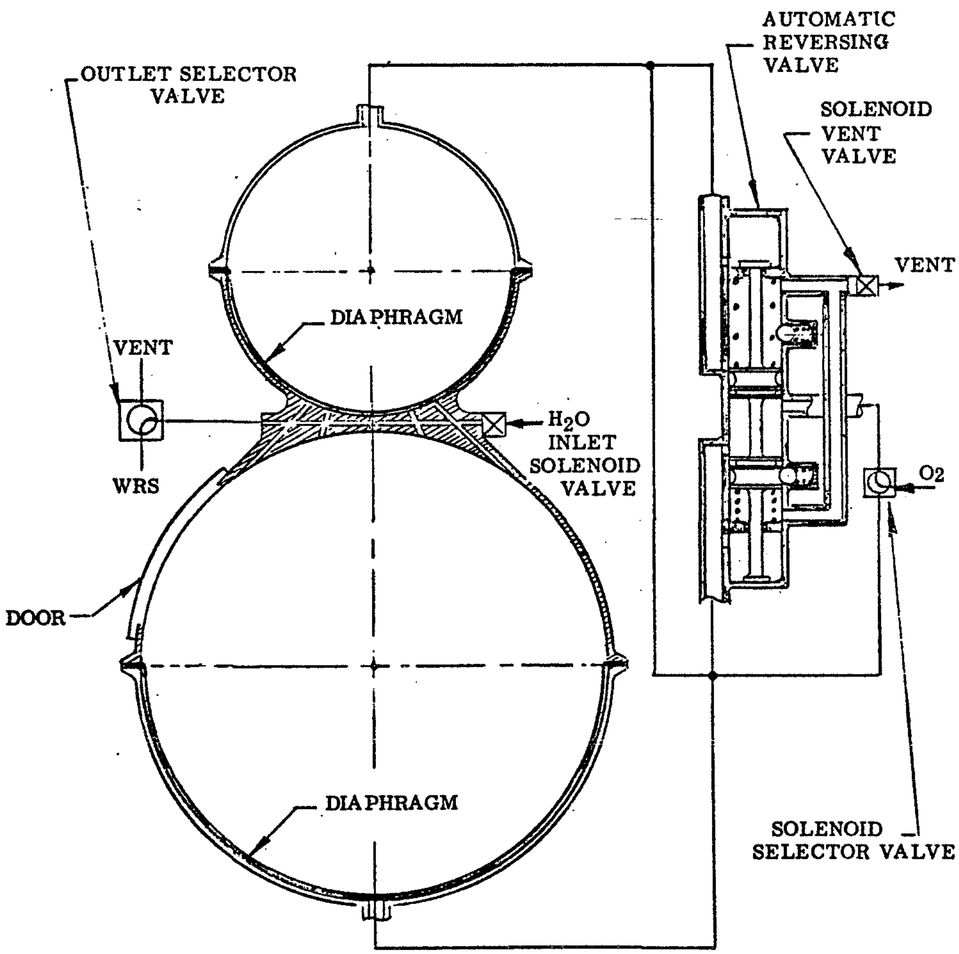


Figure 3.3-11 Diaphragm Activated Washer/Dryer

3.3.2.4.3 Conceptual Design for a Reciprocating Washer/Dryer

The washer/dryer unit depicted in Figure 3.3-12 utilizes an inner compartmented perforated chamber that is oscillated to provide washing, rinsing, and drying action and is spun to provide phase separation during the fill cycle and centrifugal force to expel the water. An electrical heat source in the static outer housing provides drying heat. A multicam timer, in conjunction with solenoid valving, sequences the wash, rinse, and dry cycles.

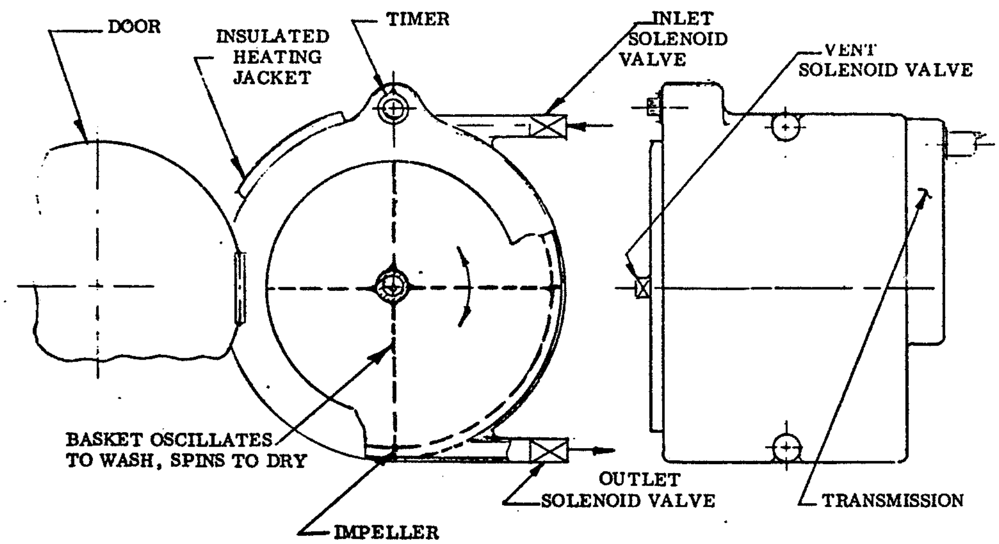


Figure 3.3-12 Reciprocating Washer/Dryer

3.3.3 The Microbial Control of Hospital and Biological Waste

Another source of contaminated waste will be generated in the hospital and biological laboratory. Surgical instruments, rubber gloves, syringes, glassware, and contaminated textiles are among those items requiring sterilization to allow their reuse. Discarded cultures, infected laboratory animals, and other infected waste require microbial control for the storage period prior to disposal. A medium sized, general purpose, laboratory sterilizer would be desirable to treat such waste on site. Several terrestrially approved methods of sterilizing laboratory and hospital waste are discussed, and conceptual designs for the various concepts presented in the following sections.

3.3.3.1 Moist Heat Sterilizer - Autoclave

High temperature saturated steam is a dependable agent for sterilization. It has the advantages of rapid heating, penetration, and moisture, which facilitate the coagulation of proteins--the mechanism by which the organisms are destroyed. The most resistant microbial forms, bacterial spores, are killed at a much lower temperature and in a shorter period of time by moist heat than by dry heat.

The autoclave, a sterilizer designed to use 250 to 270°F saturated steam under regulated pressure, is an essential unit of equipment in every hospital and in every microbiological laboratory. There is a time-temperature relationship involved in the destruction of bacteria. The sterilizing time required is a function of the nature of the material, its volume, and the type of container it is in. A common sterilizing period for an autoclave is 15 minutes at 250°F. The regulated chamber pressure, corresponding to a 250°F saturated steam temperature, is 30 psia. To attain this temperature, air within the chamber must be completely replaced by saturated steam.

The autoclave is capable of sterilizing both solid and liquid material. Surgical instruments, rubber gloves, syringes, flasked solutions, glassware, and contaminated linens are routinely sterilized by autoclaving. Materials immiscible in water and materials adversely affected by 250°F steam, such as oils and powders, are not suitable for autoclaving. One conceptual design for a zero-gravity autoclave is shown schematically in Figure 3.3-13 and in a packaged configuration in Figure 3.3-14.

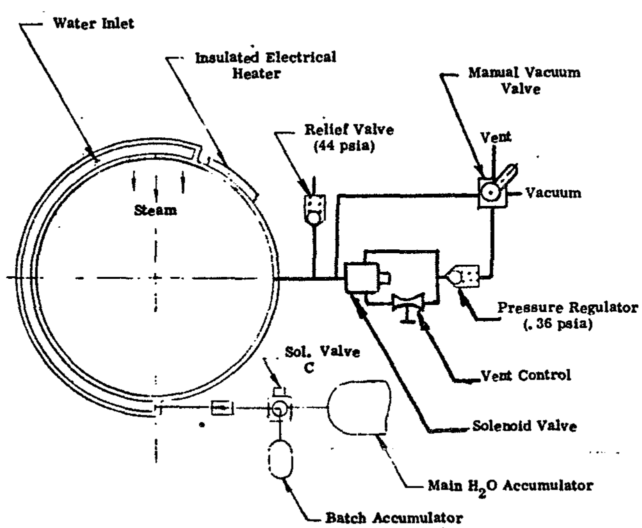


Figure 3.3-13 Autoclave Schematic

The steam chamber is a cylindrical pressure vessel with electrically heated, thermally insulated walls. A vacuum source is used to evacuate the chamber of air prior to the sterilizing cycle and to provide evaporative cooling and drying after the cycle.

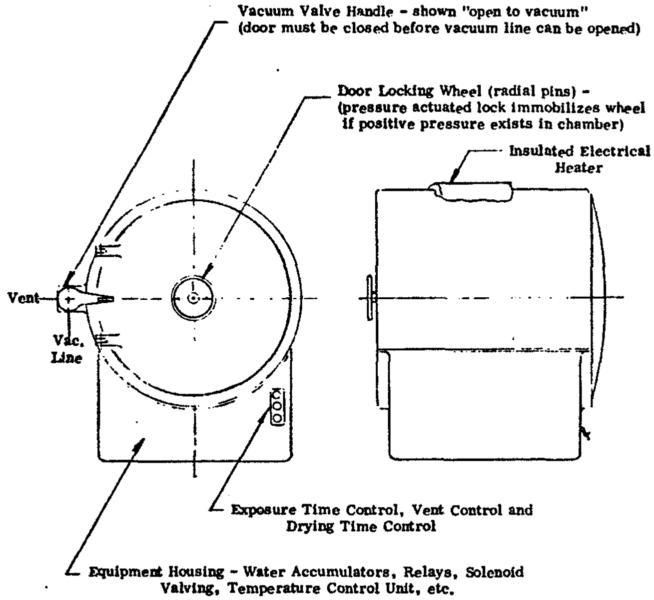


Figure 3.3-14 Autoclave Configuration

3.3.3.2 Dry Heat Sterilization

Dry heat is a good agent for sterilization; however, it requires much higher temperatures and much longer exposure times than does moist heat. For laboratory glassware, a period of 2 hours exposure at 320°F is required for sterilization. Dry heat destroys organisms through oxidation of their intercellular constituents--it denatures the organism.

Dry heat is ideal for sterilizing oils, petroleum jelly, powders, glassware, utensils, space approved fabrics, and any other solid and fluid materials not adversely affected by the high temperatures involved (320°F). Aqueous materials would not be sterilized with dry heat due to their low vapor pressure.

One conceptual design for a dry heat sterilizer appears in Figure 3.3-15. The sterilizing chamber is cylindrical in shape and has electrically heated, thermally insulated walls. In this design, a blower is used to circulate hot air through the chamber, providing a desirable feature of forced convective heating for zero-gravity operation. The blower would be operated during the initial heating phase. At the end of the sterilizing period, cabin air is circulated through the chamber to cool it.

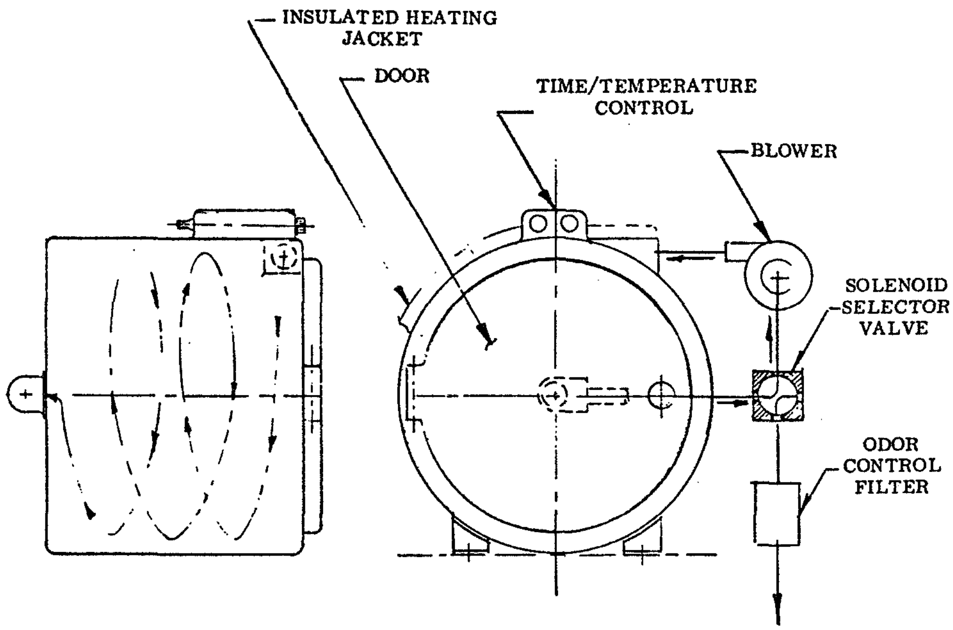


Figure 3.3-15 Dry Heat Sterilizer

3.3.3.3 Gaseous Sterilization - Ethylene Oxide

Ethylene oxide gas is a powerful chemical sterilizing agent. Bacterial spores show little resistance to destruction by this agent. It is the most widely accepted alternative to moist or dry heat, being particularly suitable for sterilizing heat-or moisture-sensitive materials. Ethylene oxide has great penetrating power and is capable of passing through and sterilizing a variety of other materials, including biological preparations, soil, plastics, and contaminated laboratory and hospital equipment.

On the negative side, pure ethylene oxide is extremely flammable in air. This condition is circumvented by using mixtures of 88% Freon 12 and 12% ethylene oxide, or 90% CO_2 and 10% ethylene oxide. Ethylene oxide sterilant mixtures are also toxic and corrosive. A very carefully interlocked chamber would be required when using ethylene oxide as a sterilant.

The ethylene oxide chamber is generally operated at 130°F. The gas pressure is 22 psia, and enough water is introduced into the chamber to obtain a relative humidity of 40%. Air is evacuated prior to introducing the sterilant mixture. The sterilization treatment must be strictly supervised because variables such as gas concentration, humidity, temperature, and process time can appreciably affect the efficiency of the treatment. All conditions must be kept standard from batch to batch. One conceptual design for an ethylene oxide sterilizer appears in Figure 3.3-16.

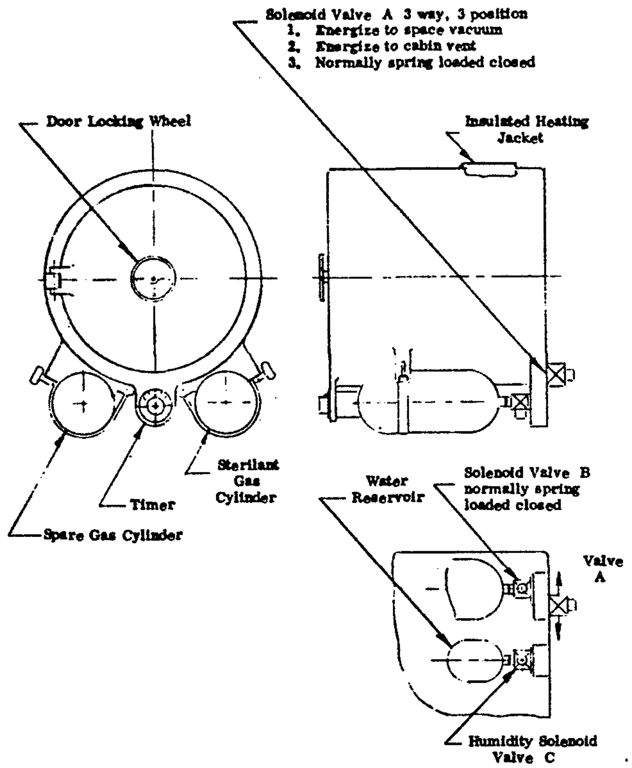


Figure 3.3-16 Ethylene Oxide Sterilizer

The unit is operated simply by opening the door, inserting the material, and setting the timer for the exposure period (usually 4 to 8 hours). The following events occur automatically:

1) Valve A opens to vacuum expelling air. Valve A closes.
2) Heater is energized, heating chamber to 130°F.
3) Valve C admits .003 lb H_2O to chamber. Valve C closes.
4) Valve B opens and sterilant gas is drawn into chamber. Valve B closes.
5) Exposure period is initiated.
6) After sterilization, heater is de-energized, and Valve A opens to vacuum expelling gas. Valve A vents chamber to cabin. Valve A closes.
7) Light signals end of cycle.

3.3.4 Waste Compaction

To provide an efficient interface with the various pretreatment and disposal alternatives, the waste generated must be compacted. A waste compactor that is suitable for spacecraft use must not compromise an essentially sterile environment. Terrestial waste compactors can be flushed with germicides, steam cleaned, or hosed down. These procedures are not feasible for spacecraft. It is felt that every effort should be made to avoid contaminating a spacecraft compactor. One approach to waste compaction is to standardize on two basic collection container designs, which would be capable of handling the bulk of the waste produced. One container would serve for soft waste and the other for hard, sharp-type waste, such as cans and glassware. Waste compaction would consist of compacting the entire chamber.

The container suitable for soft waste, such as food, foil-type packaging, dried urine or fecal bags, and most personal hygiene waste, appears in Figure 3.3-17. This container has rigid end plates and flexible, reinforced, bellowed walls. One end plate contains a hydrophilic filter. The container is capable of collecting wet or dry waste and is designed to interface with the static desiccation or refrigeration units depicted in Figures 3.3-3 and 3.3-8. The liners for the various rotary deactivation units will have the same wall construction but different end plates. Figures 3.4-4, -5, and -7 illustrate this construction. The liners and containers maintain their

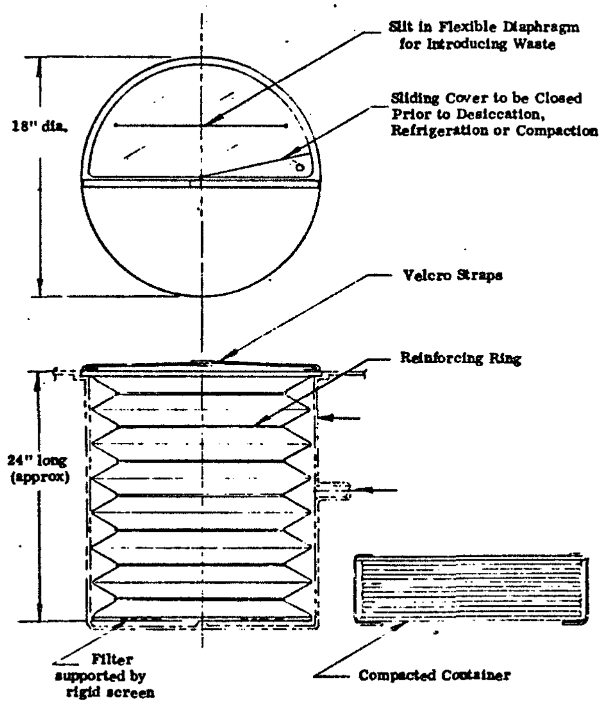


Figure 3.3-17 Bellowed Collection/Compaction Container - Soft Wall

cross-sectional dimensions upon compaction, and velcro straps are used to maintain the compacted length. This container can be packaged efficiently, both as a compacted waste package and as an expendable resupply item.

The other container, suitable for compacting cans, glassware, light bulbs, and other sharp items, appears in Figure 3.3-18. This container has rigid teflon or aluminum telescoping walls. When full of debris, the entire container is compacted and disposed of.

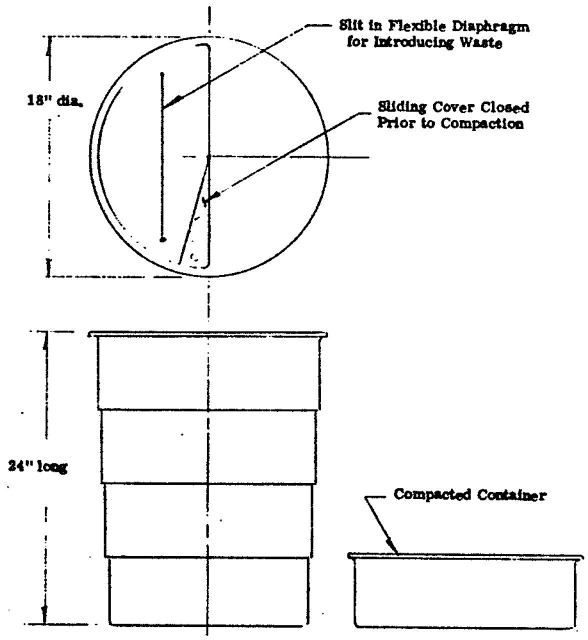


Figure 3.3-18 Rigid Wall Collection/Compaction Container

A waste compactor, designed to compact the waste containers previously described, appears in Figure 3.3-19. The cover is opened, and the waste container or containers are inserted within the unit. The cover is then closed and latched. When the unit is activated, an electrically powered, screw driver ram is energized to compact the waste.

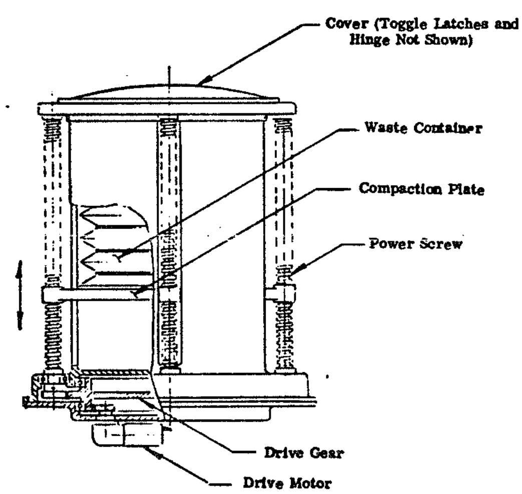


Figure 3.3-19 Waste Compaction

Dry waste could be more efficiently compacted if previously shredded. Candidate waste would include food containers, plastic bottles, and disposable clothing. One design for a dry waste shredder appears in Figure 3.3-20.

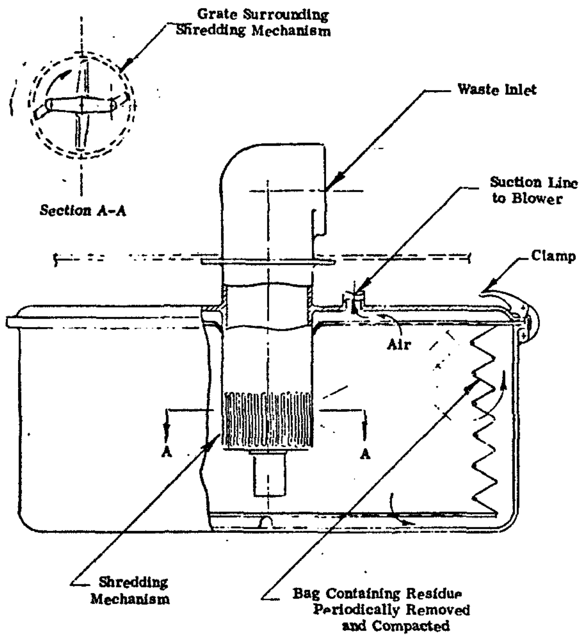


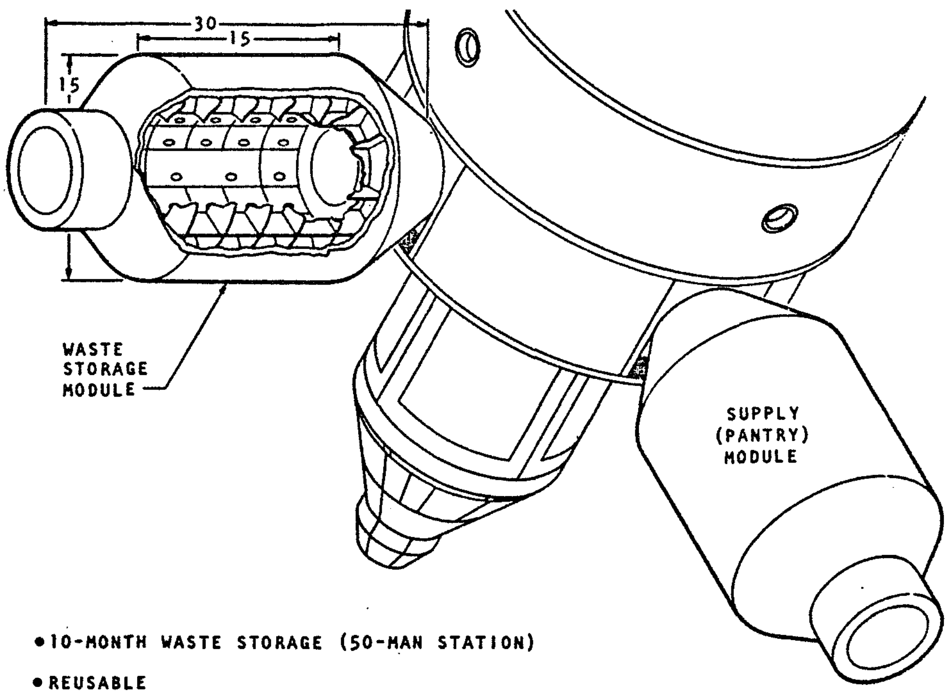
Figure 3.3-20 Dry Waste Shredder

3.3.5 Waste Disposal

The wastes that have been deactivated and stored must eventually be separated from the space station. In this section, alternative disposal methods are presented.

3.3.5.1 Waste Disposal Utilizing the Logistics Shuttle

It appears certain that the existence of large space stations is contingent on the development of a low-cost shuttle. Because the shuttle will resupply the space station and will be capable of delivering its payload both to and from the space station orbit, it is considered the prime candidate for removing the wastes generated. One approach for managing the flow of materials to and from the space station would be to dock two identical modules to the space station. One would contain the logistics supplies and the other would serve as a waste storage area. Figure 3.3-21 illustrates this concept.



- 10-MONTH WASTE STORAGE (50-MAN STATION)
- REUSABLE
- SERVICED AND MAINTAINED ON GROUND
- MINIMIZES MATERIALS HANDLING
- MAXIMUM CREW SAFETY
- NO OVERBOARD WASTE VENTING
- ELIMINATES ON-BOARD STORAGE AREAS
- FREES SHUTTLE FOR OTHER DUTIES
- INCREASES STATION AUTONOMY
- AVOIDS ON-BOARD CONTAMINATION
- SUPPLY MODULE SERVES AS WASTE MODULE WHEN EMPTY
- COLD STORAGE FOR DECEASED CREW MEMBER

Figure 3.3-21 Supply and Waste Module Concept

3.3.5.2 Vacuum Decomposition

Combustion is commonly used terrestrially for the disposal of waste, but requires too large a quantity of oxygen for space applications. An alternate approach would be to pyrolytically decompose the waste in the absence of oxygen and vent the gaseous products overboard. Approximately 88% of the total waste processed would be vented. The basic equipment required to pyrolytically decompose waste would be an insulated pressure vessel, a process heater, an overboard vent line, a process cooler and associated vent valve, thermal controls, and safety interlocks. To further reduce the residue, consisting of carbon char and ash, the carbon could be oxygen incinerated after the organics are decomposed. Approximately 97% of the total waste processed could be eliminated by this means, at the expense of .10 lb of oxygen per pound of waste. One concept for a pyrolytic incinerator appears in Figure 3.3-22.

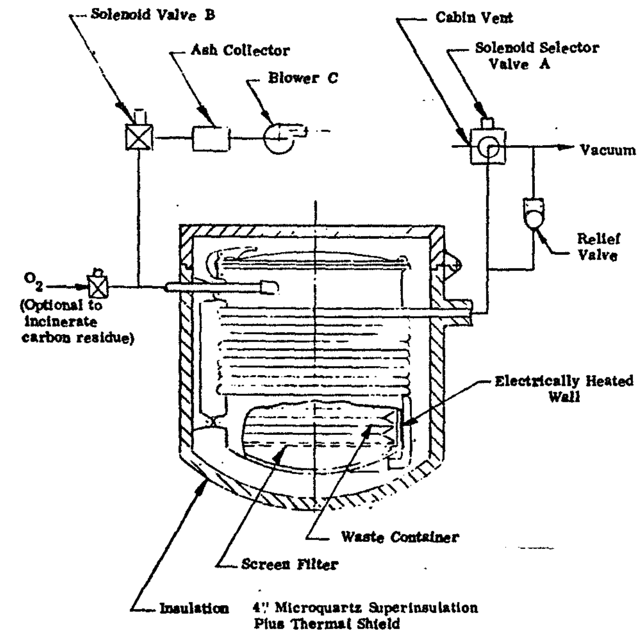


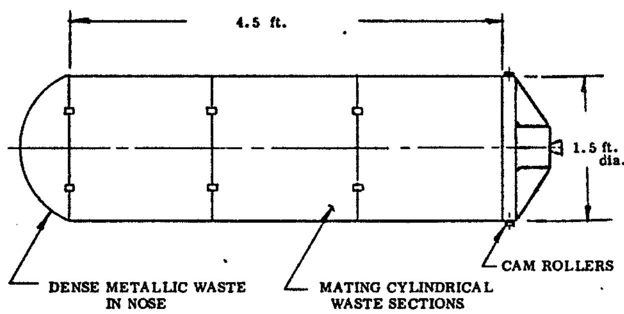
Figure 3.3-22 Pyrolytic Incinerator (Vacuum Decomposition)

There is concern about the possibility of a debris atmosphere surrounding manned spacecraft. Work is continuing in this area in an effort to quantify the effects of the various sources of debris. The effluents that contribute to the contamination cloud around a space station are atmospheric leakage and dump, propellant exhaust, and liquid and condensable vapor dump. The immediate effect of fluid discharges will be to create an artificial atmosphere in the vicinity of the spacecraft. Liquid and condensable vapor venting are potentially the most harmful with respect to optical experiments because considerable light scattering could result from ice particles formed during the dump. The problem would be most severe for observations of dim light sources such as the solar corona or inner zodiacal light. In addition to the scattering problem, there is additional concern that there could be layers of contaminants deposited on exposed optical surfaces. The long-term effect of a tenuous atmosphere surrounding the station will be a gradual, but cumulative, surface depositing process. It could prove unwise to consider any waste disposal method that involves the intentional venting of large quantities of condensable vapors.

3.3.5.3 Waste Disposal Utilizing a Solid Propellant Rocket

The uncontrolled jettisoning of waste into earth orbit is to be avoided. For high-altitude orbits, where all estimates of atmospheric drag are negligible, orbital lite times are measured in years. A large quantity of waste packages in orbit could impose a potential hazard. In addition, all objects in orbit are identified with a radar signature. This task would be greatly magnified by the injection of numerous waste canisters of similar geometry into orbit. It is felt that only the controlled jettisoning of waste should be considered.

One approach would be to use a solid propellant rocket motor and jettison the waste to earth for aerodynamic incineration. A state-of-the-art propulsion system weight .061 times the weight of containerized waste jettisoned would be required. One conceptual design for a waste rocket appears in Figure 3.3-23.



Rocket Motor Weight: $W_M = .061\ W_w = .06\ (318) = 19.40$ lbs.

Rocket Motor Volume: $W_M = .000612\ (318) = .195\ Ft^3$

Fuel Weight: $W_F = W_M/1.1361 = 17.1$ lbs.

Fuel Vol. (ref): $V_F = 17.1$ lbs. $\div\ 108\ lb/ft^3 = .158\ ft^3$

Total impulse $= I\ W_F = 260\ (17.1) = 4450$ # sec.

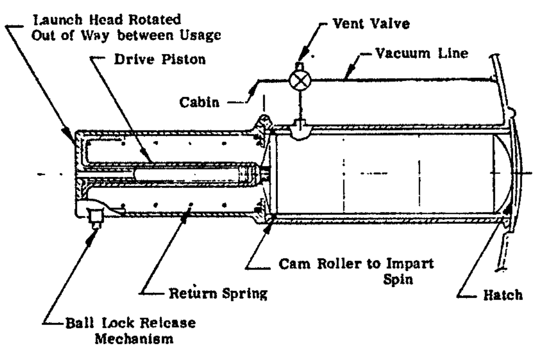
Thrust for 20 sec. burn $= 4450 \div 20 = 223$ lbs.

Figure 3.3-23 Waste Rocket to Jettison 318 lbs of Waste to Earth from 300 n m Circular Orbit

Radioactive material, as an item of waste, requires special consideration. It is not desirable to consider burnup by ablation during reentry and atmospheric dispersion of the residue fissionable materials. Some studies have indicated that incineration alone is not a sufficient guarantee that the hazards of radioactive fuel deposition on earth have been eliminated. Controlled reentry for burial in an isolated section of the ocean is feasible; however, certain hazards are involved due to possible malfunctioning return vehicles. An alternative solution would be to jettison the radioactive waste to a higher earth orbit with a lifetime sufficient to permit effective radioactive decay of the residue fissionable materials.

Another approach would be to jettison the waste to a solar orbit. The minimum velocity increment required to effect this transfer from a 270 N.M. circular orbit to a solar orbit is 10,342 ft/sec. If a solid propellant rocket motor were used to effect the transfer, it would require a motor 4.171 times the weight of the containerized waste jettisoned.

To prevent contamination of sensitive surfaces on the space station from the combustion products of the retro-motor, launch provisions on the space station must provide for adequate separation distance at motor ignition. They must also provide for spin-up of the waste package prior to ejection in order to maintain the proper orientation during this coast phase of flight and to nullify the effect of thrust misalignment. One configuration suitable for spin ejecting a waste rocket appears in Figure 3.3-24.



Operation:

Rotate launch handle to "eject" position (not shown). The following events occur automatically:

1. Launch tube is vented to space and then hatch opens.
2. Launch piston is released and rocket is spin ejected. Cabin pressure provides launch force. Helical groove in launch tube imparts spin.
3. Hatch closes.
4. Launch tube is vented to cabin and spring retracts launch piston.

Figure 3.3-24 Launch Tube for Spin Ejecting Waste Rocket

3.4 WASTE CONTROL AND HOUSEKEEPING

3.4.1 Introduction

The purpose of space station housekeeping and waste control is, primarily, the maintenance of a clean, sanitary, and habitable environment to sustain the health, safety, and efficiency of crew members. An additional goal of the housekeeping program is the salvage, reprocessing, and ultimate utilization of on-board wastes, where feasible, to reduce the magnitude of the logistics problem. Any systems, procedures, or equipment used for housekeeping and waste control should be applicable in both zero and partial gravity environments or should be readily alterable to function in either. Furthermore, procedures and materials used must not compromise the integrity of the environment control and life support systems nor release objectionable, noxious, or toxic odors, vapors, particulate matter, or microorganisms.

The design of housekeeping tasks to be performed in zero gravity must consider the problems associated with locomotion and shifting centers of mass of the cargo carrying crewman. Locomotion aids, handholds, foot retention devices, handrails, and auxiliary transportation equipment are required for effective operations.

In artificial gravity (induced by rotation of the station or of station segments), locomotion and task performance are hindered by Coriolis accelerations and vestibular optical illusions, which could produce vertigo and disorientation. While these effects can be minimized by training and experience, the design of crew tasks and the arrangement of the space station interior must consider these effects while seeking to ameliorate them.

Section 6.0 of Volume I of the Data Book presents the detail results of the study and the data generated. A summary of the results of the study is as follows:

- Identification of staffing requirements for waste control and housekeeping on 12-, 50-, and 100-man space stations
- Desirability of in-orbit training programs for retention of experienced personnel
- Identification of procedures and supplementary aids to locomotion and waste handling
- Problems and ameliorative techniques associated with waste handling task performance in zero and in partial gravity
- Safety and accident prevention in waste control and housekeeping activities
- Definition of detailed tasks and performance times in zero and partial gravity for 12-, 50-, and 100-man space stations

- Methods of calculating manpower requirements for waste control and housekeeping activities
- Conceptual designs of containers for various types and classes of waste materials
- Conceptual designs of automatic and mechanized transfer systems and their applicability to space station configurations

3.4.2 Personnel

As the space station evolves into the space base, the nature of the crew's system operation assignments and housekeeping functions change from those requiring greater flexibility and cross-training to those involving more specialized skills and task assignments. In the 12-man station, each crew member performs housekeeping functions associated with his system responsibility and his personal requirements.

Intersystem housekeeping functions -- transfer, processing and deactivation, packaging, storage, and disposition -- will be performed on a scheduled, rotating basis by each crewman with the exception of the commander. Table 3.4-1 shows proposed crew assignments, both normal and contingency, for a 12-man station (Ref. Earth-Orbiting Space-Base Crew Skills Assignment, R. T. Gundersen, NASA TM X-1982).

In the 50- and 100-man space base, the increased time requirements and dispersal throughout the base requires that housekeeping functions be performed by specifically billeted crew members who are trained in the techniques of space base housekeeping in zero and partial gravity. Table 3.4-2 shows proposed crew assignments for those personnel directly involved in housekeeping and waste control for the 100-man station, again from NASA TM X-1982.

3.4.2.1 Personnel Considerations

Personnel selection for prolonged space base housekeeping functions poses the problem of retention of such personnel in lower status duty positions. The psychological and physiological qualifications for space duty make improbable the willingness of selected personnel to continue indefinitely in such positions. Rather than incurring the loss of desirable skills and abilities by returning these crewmen to Earth more frequently than other personnel, it is desirable to provide in-orbit training programs leading to more attractive billets. Curricula and program duration can be tailored to match crew rotation schedules and to utilize effectively the space skills already developed.

TABLE 3.4-1 CREW ASSIGNMENTS – 12 MAN STATION (Inflight Crew Operations)

Crewman position	Nominal inflight condition	Critical flight condition	Subnominal inflight condition	Contingency condition	Emergency condition
1. Commander	EOSB manager/navigator (evaluation, decision-making) - commands and controls space base	EOSB manager/navigator, logistics officer	Communicator (comm. and DMS), test subject	Electrical engineer (experiments, unscheduled maintenance)	Damage control officer
2. Deputy commander	EOSB deputy mgr./navigator - G&N responsibilities	Navigator/logistics control officer	Experimenter/test subject (biomed., biology), EVA and IVA specialist	Chemical engineer	Safety officer, EVA
3. Flight surgeon	Medical monitor, psychological experimenter, med. experimenter	Sick bay physician (first aid treatment, sick treatment, minor surgery)	Medical monitor (sanitation, hygiene, atmosphere gas analysis, first aid instruction)	Med. experimenter (biomedicine, biotechnology)	Radiation protection and decontamination, emergency surgery, sick bay
4. Power systems officer	EPS control console operator (monitor, control, observe, and interpret)	EPS monitor	Experiment observer, comm. interpreter	EPS and related experiment support, maintenance engr./repairman	Damage control party or command-center monitor
5. Systems engineer	Systems manager and flight operations engineer (monitor, check, adjust, and assess system operation)	Communicator/DMS	Maintenance engr. (inflight checkout and scheduled subsystems maintenance)	Maintenance engr. (unscheduled maintenance, experiment support) - reprograms	Damage control party
6. Technical director	Chief scientist/experimenter (monitor, setup, and operation) - command and control of experiments and related equipment	Experimenter (biotechnology, biomedicine, etc.)	Experimenter (biochemistry, physics, chemistry), EC/LS and crew subsystem consultant	Experimenter	
7. OLC mgr.	Operations analyst/supply specialist (plans and schedules)	Logistics specialist	Operations evaluation (programs daily operations), test subject	General engr./mgr.	Damage control party

TABLE 3.4-1 (Cont'd)

(Inflight Crew Operations)

Ref.: Earth Orbiting Space Base Crew Skills Assessment, R.T. Gundersen, NASA TM X-1982

Crewman position	Nominal inflight condition	Critical flight condition	Subnominal inflight condition	Contingency condition	Emergency condition
8. Operations engr. A	Electronics engr./console operator (monitor, control, observe, and interpret)	Experiment and systems support engr. (comm., DMS)	Maintenance engr. (electronic equipment), test subject	Instr. and elec. engr. (unscheduled maintenance)	Command center monitor
9. Operations engr. B	Electromech. engr./ console operator (monitor, control, observe, and interpret)	Experimenter/observer, interpreter, photographer	General experimenter/ systems maintenance engr., test subject	Technician/repairman	Command center monitor
10. Experiment specialist	Experimenter/ photographer	Optical physicist/ experimenter (astronomy)	General experimenter (monitor setup, operations, programing) (stellar, solar, radio)	Optical repair	Damage control party
11. Communications officer	Comm. mgr. (control station and DMS)	Communicator (comm. interpretations on station and to the ground)	Elec./instr. engr. (comm. equipment maintenance, OCS, crew station controls and panels, caution and warning system, DMS), evaluator	Electronics/instr. engr. (unscheduled maintenance, experiment support)	Communicator (caution and warning)
12. DMS officer	Assist. comm. chief (DMS mgr. - onboard analysis, filtration, transmission, or rejection of data)	Monitors incoming data, edits and evaluates data, manages tape recording and data program changes	Drilling and crew-training specialist, data collection, storage, evaluation, and editing	Same as position no. 11	Communicator (phone talker, TV monitor)

TABLE 3.4-2 HOUSEKEEPING CREW RESPONSIBILITIES-100 MAN STATION

Crewman and Work Responsibility	Crew Skills: Primary	Crew Skills: Special
1. Systems Housekeeping Supervisor Subsystems servicing Maintenance and repair	Electromechanical technician	Maintenance, service and repair specialist
2. Officers' Steward Room and washroom cleanup Barber	Steward	Barber Damage and fire control party member
3. Officers' Steward Room and washroom cleanup	Steward	Damage and fire control party member
4. Habitability Specialist Work/sleep-cycle; food-consumption; clothing-usage; garbage-collection; light-noise-and vibration-level; and traffic-counter-readout monitoring	Architect	Engineer
5. Janitor Overall cleaning of space base	Janitor	Custodian

3.4.2.2 Zero-Gravity Procedures and Aids

Housekeeping and waste handling procedures in the 12-man station will be primarily manual, with simple mechanical aids to task performance. Special containers, grasping implements, vacuum cleaners, and clothesline-type transporting systems can be used; these are illustrated in Volume I of the Data Book with examples presented in Section 3.4.2.3 of this report. Handrails, handholds -- both fixed and portable -- foot retention devices, and tether attachments will mate with special receptacles or grids along passage areas and work stations.

Whereas the unencumbered astronaut can soar along clear passage areas, the addition of cargo carrying requirements introduces locomotion problems associated with shifts in centers of mass of the man under various load conditions. Pitching, rolling, and yawing moments produced by changed inertial relationships will limit the effectiveness of manual waste container transport. To minimize these problems, several methods are proposed:

- A rail and trolley system equipped with a handhold can be used to stabilize the astronaut-cargo system during soaring. Acceleration is provided either by astronaut push-off or an internal drive motor, with braking features integral with the handhold. This system can also be used to transport either the cargo or astronaut only.
- Containers used for given material loads of known density can be marked to identify center of mass for easier handling. For variable waste and containers, waste packages can be passed through a weighing station to locate and identify the center of mass.
- Maximum use of handrails, handholds, and other supports. The astronaut must learn to apply proper forces at proper rates to avoid body rotations and to permit controlled decelerations.

3.4.2.3 Partial Gravity Problems and Ameliorative Techniques

The introduction of artificial gravitational force by rotating the space station or station segments subjects the astronaut to Coriolis acceleration effects and to vestibular-ocular illusions that will degrade his performance. Coriolis effect results from the addition of an acceleration vector, generated by head movement, to the gravity vector generated by station rotation. The vestibular organs sense the resultant vector magnitude and direction, producing exaggerated pitch, roll, or yaw sensations to which the individual responds as though these were, in fact, actual body displacements. Visual illusions include apparent rotations and displacements of objects and environment with resulting vertigo and disorientation. The bending, turning, torso and head movements normally associated with housekeeping tasks will subject the astronaut to

Coriolis accelerations and the attendant problems. Several procedures are recommended to alleviate these difficulties:

- Initial selection of space station or base personnel should include tests of the vertical semicircular canals. Thus far, only the horizontal canals have been tested as part of labyrinth test procedures (Ref. Experimental Tests on Isolated Individual Semicircular Canals as a Fitness Test for Astronauts, H. Decher, Aerospace Medicine, November 1969).
- The dynamic cross-coupling effects of accelerations producing Coriolis effects can be minimized by proper head stabilization. Tests conducted on spin recovery capability of pilots who maintained an erect head posture (relative to the outside visible horizon) during deliberately induced aerodynamic spins indicate that such a procedure facilitates spin recovery (Ref. Origin, Significance, and Amelioration of Coriolis Illusions from the Semicircular Canals: A Non-Mathematical Appraisal, G. Melvill Jones, Aerospace Medicine, May 1970).
- Coriolis acceleration effects are reduced when head motions are parallel to the rotational axis of the space vehicle. It is recommended that a study be performed of space base rotation cycles, acceleration vectors, and gravity gradients combined with analysis of astronaut motion sequences, locomotion paths, techniques, and work cycles to produce optimum housekeeping practices designed to minimize Coriolis effects. Figure 3.4-1 depicts gravity levels achievable with rotating space stations and bases and defines a comfort level for human occupancy. In the particular study cited, a constant level of 0.3 g was selected, determined by the shortest spin radius from the vehicle center of gravity to the mission module. Angular velocities corresponding to larger spin radii are shown to maintain the 0.3 g level.
- Housekeeping aids, tools, and devices would minimize bending and turning body motions.
- Crew training and experience in simulated partial gravity will provide ameliorization with the techniques of walking, climbing, turning and bending and general coordination of visual and motor activities.

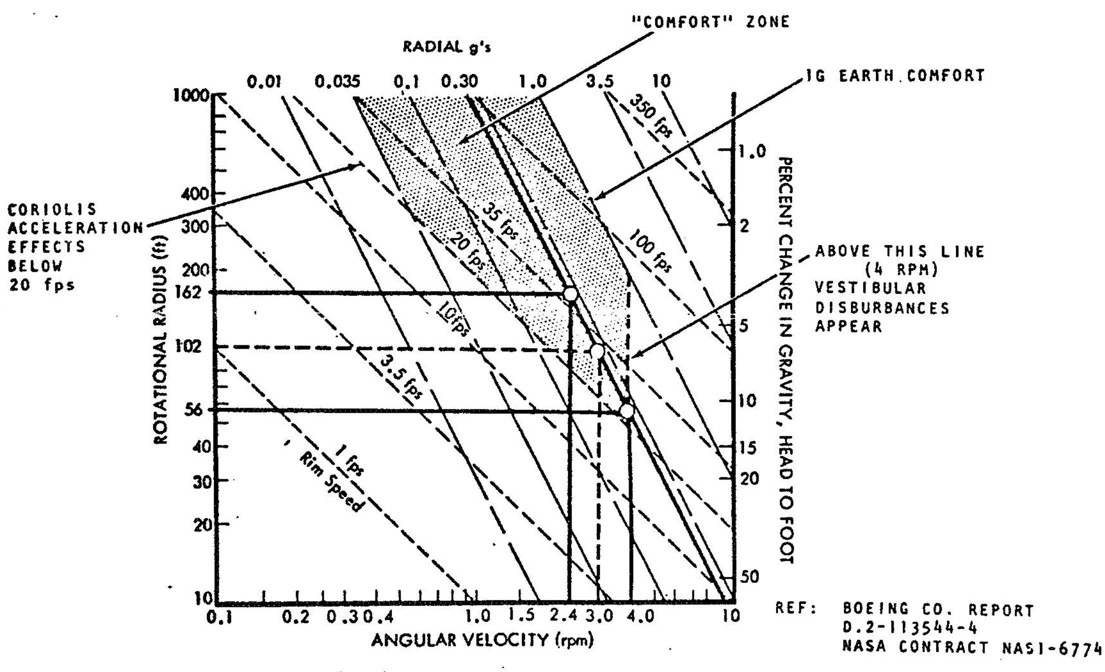


Figure 3.4.-1 Rotational Parameters and Comfort Zones

3.4.2.4 Safety and Accident Prevention

Waste control and housekeeping requirements for operational effectiveness and safety should be incorporated in space station and base design. Among the potential causes of accident or injury are: fire or explosion caused by loss of control during pyrolysis, inadvertent mixture of chemicals with hypergolic properties, or rapid oxidation in the presence of ozone; electrical hazards; mechanical damage from operating equipment used in waste handling; food or water contamination; leakage from radioactive laboratory materials; transfer of harmful microorganisms via the waste transport system; and personnel error.

Among the methods for reducing accident and injury are: adequate training in the safe techniques of waste management and fire control; design for containment and isolation; proper escape provisions; adequate warning indicators and alarms; reliability and low failure rates of equipment; and regular scheduled inspection maintenance. In addition, safety precautions should be established for storing and handling radioactive wastes and wastes containing harmful microorganisms. Recommended safety levels are provided in Volume I of the Data Book.

3.4.3 Waste Handling Task Analyses

A functional analysis was performed to identify principal functions associated with waste handling activities. These functions were then analyzed to define the detailed task and subtask elements for purposes of developing a detailed task-time analysis and to form a basis for conceptual designs of waste containers and transfer equipment.

The principal functions identified are:

- Waste collection and pickup
- Waste transfer to storage
- Waste sorting for processing and disposal

These top level functions were subdivided into their basic task elements for the various sized space stations and performance times estimated, with accompanying rationale for 1-g, 0.2-g, and 0-g environments. The detailed task-time analyses are presented in the Data Book, Volume I, Tables 6-5 through 6-12. Tables 3.4-3 through 3.4-6 are selected pages from these tables and are presented to illustrate the variables included in the analysis and the data presentation format.

TABLE 3.4-3 SAMPLES OF TASK TIME ANALYSIS DATA

TASK - TIME ANALYSIS

TASK: WASTE PICKUP - ZERO GRAVITY (PO)

SUBTASK NO.	SUBTASK	TASK ELEMENT NO.	TASK ELEMENT	UNIT TIME - SECS 0 G	0.2 G	1 G
PO-1	Secure position at waste receptacle	PO-1.1	Grasp hand hold.	4		2
		PO-1.2	Insert both feet into foot restraints.	10		5
		PO-1.3	Release hand hold.	2		1
PO-2	Secure carryall bag and open for use	PO-2.1	Stand carryall vertically against side of receptacle.	10		5
		PO-2.2	Secure loops of mesh bag to side of receptacle.	12		6
		PO-2.3	Unclasp spring clips holding carryall handles.	6		4
		PO-2.4	Open mesh bag to receive waste container.	10		6
PO-3	Insert hand into waste receptacle	PO-3.1	Press fingertips of one hand against iris of receptacle lid.	5		3
		PO-3.2	Open iris and insert arm into receptacle.	6		4
PO-4	Close or seal inner container (a) Flexible waste container (b) Impermeable waste container	PO-4.1	Remove backing from seals.	15		10
		PO-4.2	Deposit into container	3		2
		PO-4.3	(a) Unfasten one side of container	6		4
			(b) Free seal flap	8		5
		PO-4.4	(a) Press seal edges of opposite side	15		10
			(b) Press seal flap over opening in container.	9		6

TABLE 3.4-4 SAMPLE OF TASK TIME ANALYSIS DATA

TASK - TIME ANALYSIS

TASK: Waste Transfer - Partial Gravity (TG) - 12 Man Station

SUBTASK NO.	SUBTASK	TASK ELEMENT NO.	TASK ELEMENT	UNIT TIME - SECS 0 G	0.2 G	1 G
TG-1	Carry Load Toward storage area	TG-1.1	Walk along deck holding handrail for stability. Average speed-3 fps, unit = 10 feet. Grasp carryall by long handles.		3.33	3.33
		TG-1.2	Descend between decks Average speed= 2 fps Unit = 10 feet		5.0	5.0
		TG-1.3	Ascend ladder between decks at average speed of 1 fps. Unit = 10 feet		10	10
		TG-1.4	Make 90° turn		3	2
		TG-1.5	Stop, set load on deck		4	3
TG-2	Open hatch	TG-2.1	Grasp hatch handle, pull open		6	5
		TG-2.2	Secure hatch		3	2
TG-3	Transfer load through open hatch	TG-3.1	Step through hatch		7	5
		TG-3.2	Turn, grasp carryall handles		4	3
		TG-3.3	Pull and guide load through hatch, place carryall on deck		12	10
TG-4	Close hatch	TG-4.1	Release hatch		2	2
		TG-4.2	Pull hatch shut		4	3
		TG-4.3	Lock hatch		3	3
TG-5	Carry load toward storage area		See TG-1			
TG-6	Transfer load through airlock	TG-6.1	Check pressure in airlock		3	3
		TG-6.2	Unlock hatch		6	5

TABLE 3.4-5 SAMPLE OF TASK TIME ANALYSIS DATA

TASK - TIME ANALYSIS

TASK: Waste Transfer - Zero Gravity (TO) - 50-100 Man Station

SUBTASK NO.	SUBTASK	TASK ELEMENT NO.	TASK ELEMENT	UNIT TIME - SECS 0 G	0.2 G	1 G
TO-17	Use conveyor or aids to arrive at offloading point	TO-17.2	Grasp handrail, propel self parallel to deck at 3 fps. Unit = 10 feet	3.33		3.33
		TO-17.3	See TO-11.2	5		5
		TO-17.4	See TO-11.3	4		2
TO-18	(a) Transfer wastes through hatch	TO-18.1	Grasp hand hold at hatch	4		2
		TO-18.2	Pull lock handle with free hand	6		3
		TO-18.3	Open hatch and secure	6		3
		TO-18.4	Grasp carryall, enter hatch feet first	20		10
		TO-18.5	Turn and guide carryall through hatch	30		10
		TO-18.6	Place carryall on deck and secure	6		2
		TO-18.7	Release and close hatch holding hand hold at hatch exit	15		5
		TO-18.8	Lock hatch	6		3
TO-18	(b) Transfer wastes through airlock	TO-18.9	Secure carryall at entrance to airlock	6		2
		TO-18.10	Check air pressure in airlock	3		3
		TO-18.11	Equalize air pressure if required	30		30
		TO-18.12	Open airlock, retain hand hold	6		3
		TO-18.13	Enter airlock	20		10
		TO-18.14	Guide carryall into airlock	24		8

TABLE 3.4-6 SAMPLE OF TASK TIME ANALYSIS DATA

TABLE TASK - TIME ANALYSIS

TASK: WASTE SORTING AND DISPOSITION - ZERO GRAVITY (SO) - 12, 50, 100 MAN STATION

SUBTASK NO.	SUBTASK	TASK ELEMENT NO.	TASK ELEMENT	UNIT TIME - SECS 0 G	0.2 G	1 G
SO-1	Enter waste storage area	SO-1.1	Grasp handrail. Trail carryall to storage bins	6		2
		SO-1.2	Open carryall. Prepare to load.	20		10
SO-2	Observe container code	SO-2.1	Read code on container	3		3
		SO-2.2	Refer to master code list for container destination.	10		10
		SO-2.3	Set container near carryall and secure	6		2
		SO-2.4	Select containers having identical codes. Stow like containers together.	TBD		TBD
SO-3	Load carryall with containers of same code	SO-3.1	Place each container in open carryall with container axis parallel to long handle	18		6
		SO-3.2	Repeat until carryall is filled	90		30
		SO-3.3	Close and secure carryall	16		8
SO-4	Transport carry-all to designated area		See Task Elements TO-1.1 through TO-1.5			
SO-5	Deposit containers at designated site		See Task Elements TO-7.1 through TO-7.3			

3.4.3.1 Waste Handling Manpower Calculations

Equations have been developed for the calculation of manpower requirements for the performance of collection, sorting, and transfer routines.

Manpower requirements for collection are derived from the equation:

$$T_c = F_1 (P_1 U_1 + P_2 U_2 + \dots P_n U_n)$$

where: T_c = total time in manhours for a given container during calendar period

P_1 = pickup task element

U = unit time per task element

F_1 = frequency of pickup of given container during calendar period

Total manhours required to service all waste receptacles during a given calendar period are:

$$MH = \sum T = T_1 + T_2 + \dots T_n$$

where: $T_{1}, {}_{2}, \dots {}_{n}$ is total time per container

To determine the manpower required in the performance of transfer tasks, the following equation is used:

$$T_t = \frac{m}{10} (3.33) + \frac{n}{10} (5) + t (4) + h (45) + l (120) + x (u),$$

where: T_t = total time per transfer cycle

m = number of feet travelled parallel to deck

n = number of feet travelled perpendicular to deck

t = number of right angle turns per cycle

h = number of hatches negotiated per cycle

l = number of airlocks negotiated per cycle

x = other task elements of load handling

u = unit time in seconds per element

The constants used, i.e., 3.33, 5, 4, 45, etc. are derived from the data developed in the detailed task-time analyses (Ref. Volume I), for the particular task element considered.

Manpower required for sorting operations can be determined from:

$$T_s = F_s (S_1 U_1 + S_2 U_2 + \ldots . S_n U_n)$$

where: T_s = time spent in sorting operations in manhours per calendar period

F_s = frequency of sorting per calendar period

S = sorting task element

U = unit time per task element

Figure 3.4-2, Task-Time Worksheet Form, and Figure 3.4-3, Personnel Requirements Analysis Form, are formats developed for the application of task-time data and housekeeping manpower data to the determination of crew time and estimates of total manpower required per month or per year.

3.4.3.2 Waste Containers

The various types of waste generated at architectural subdivisions of the space station have been identified and categorized by state and attributes. Volume II of the Data Book contains detailed operational descriptions, types, and quantities of wastes generated aboard 12-, 50-, and 100-man space stations. The containers for these wastes must be designed for compatibility with the type of waste projected. Table 3.4-7, Waste Attributes and Container Concepts, relates the state and condition of different types of waste to the relevant container characteristics. Figures 3.4-4 through 3.4-8 depict conceptual designs of containers for space application. Sizes and load capacities of candidate containers are shown in Table 3.4-8, Container Data for Manual Transfer.

3.4.3.3 Waste Transfer Systems

Conceptual designs have been developed for waste transfer systems applicable in either zero or partial gravity environments. Certain of these concepts are also capable of transferring crew members and passengers. The baseline transfer capabilities include:

- Intrastation transfer
- Interstation transfer
- Shuttle or cargo module to station transfer
- Transfer between unattached orbital elements
- Transfer from station to alternate earth or moon and sun orbits

TASK-TIME WORK SHEET

Time-Hrs______

Task:______________________________

Station Area:______________ Space Serviced:______________ Loc:__________

Equipment Used: (1) On Site______________ (2) Portable______________

Route: From______________ To______________ Via______________

Sub Task No.	TASK ELEMENTS	Unit Time	No. of Units	Subtask Time

Scheduled:______________ Completed:______________

Figure 3.4-2 Task-Time Worksheet Form

Analysis of Housekeeping Personnel Requirements											Personnel. Required______	As of Date______
Station Area	Space Serviced	Pick Up Task			Transfer Task			Sorting and Interface			Total Manhours	
		Time	F	MH	Time	F	MH	Time	F	MH	☐ Mo	☐ Yr
Living	Lounge											
	Recreation											
	Halls											
	Bathroom											
	Bedroom											
	Study/Library											
Services	Dispensary											
	Laundry											
	Supply											
	Maintenance											
	Power											
	Equipment											
	Barber											
	Airlocks											
	Storage											
	Gym											
Food	Kitchen											
	Dining Room											
	Food Storage											
	Snack Bar											
Work	Control											
	Communications											
	Computer											
	Laboratories											
	Shops											
	Offices											
	Inspection											
	Docking											
	Photo Support											
	Animal Housing											
	Agric Study Area											
	Airlocks											
	TOTALS											

Frequency Code:
D-Daily
2D-Twice Daily
W-Weekly
2W-Twice weekly
M-Monthly
2M-Twice Monthly
M2 - Every 2 Mos
M3 - Every 3 Mos
Y - Yearly

$$\text{Personnel Req'd.} = \frac{\text{Monthly MH}}{208}$$

$$\text{Personnel Req'd.} = \frac{\text{Yearly MH}}{2496}$$

Figure 3.4-3 Personnel Requirements Analysis Form

TABLE 3.4-7 WASTE ATTRIBUTES AND CONTAINER CONCEPTS

Waste State \ Waste Condition	Non-Toxic Sterile, or Inert	Toxic, Noxious Contaminated or Active	Hot (Above Safe Skin Contact Temperature)	Cold (Below Safe Skin Contact Temperature)	Radioactive
A. Solid Metal, plastic, glass, textile, paper Flexible, rigid sheet, rod, tube Spongy, bulky, granules, sharp, brittle, dense	Flexible Bag	Sealable Impermeable Bag	Insulated Container	Insulated Container	Shielded Container
B. Liquid Acid, alkali, oil, water, emulsion, gel.	Flexible Bag	Sealable Impermeable Bag	Bag in Insulated Container	Bag in Insulated Container	Bag in Shielded Container
C. Gas	Flask	Flask	Flask in Insulated Container	Flask in Insulated Container	Flask in Shielded Container
D. Mixture - Solid and Liquid Suspension, slurry	Flexible Bag	Sealable Impermeable Bag	Bag in Insulated Container	Bag in Insulated Container	Bag in Shielded Container
E. Mixture - Liquid and Gas	Flask	Flask	Flask in Insulated Container	Flask in Insulated Container	Flask in Shielded Container

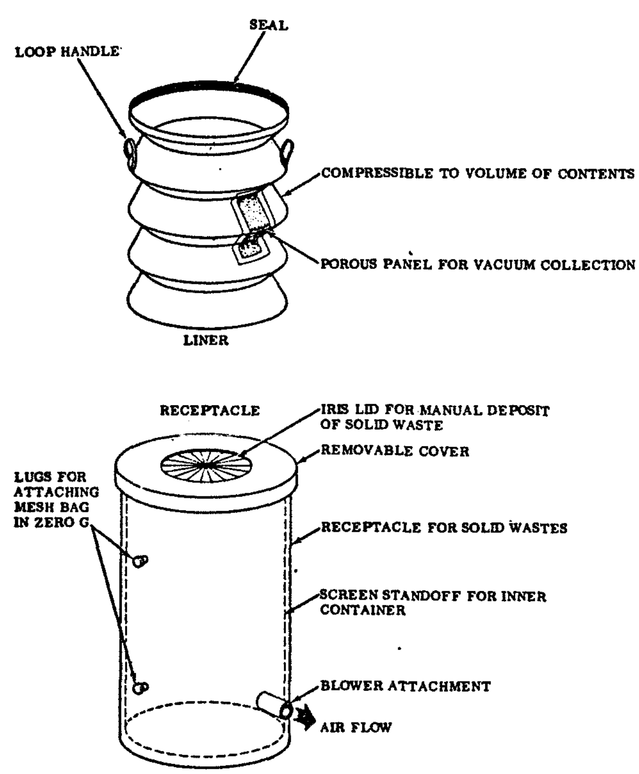


Figure 3.4-4 Concept of Container for Non Toxic Waste

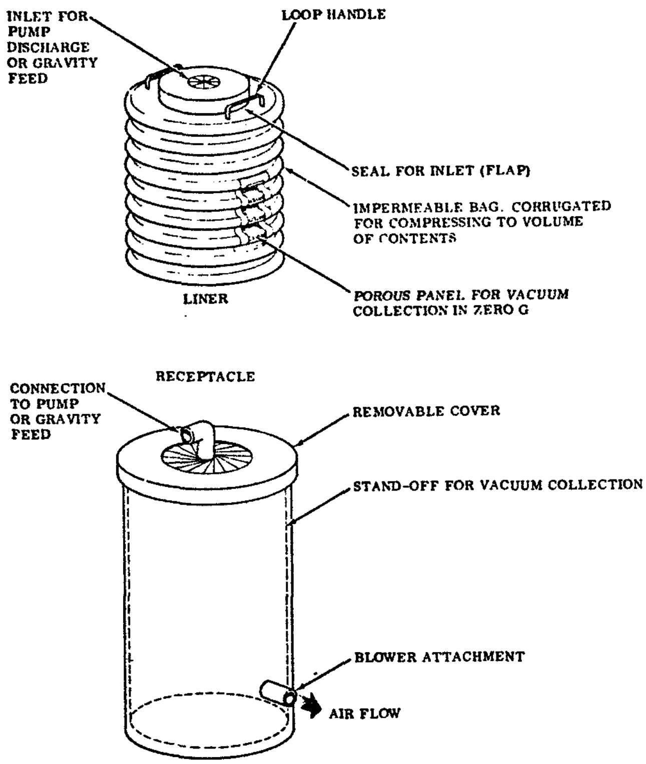
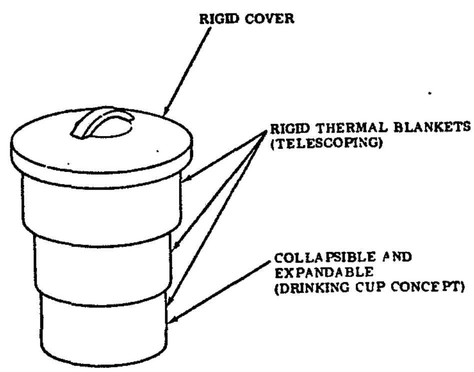


Figure 3.4-5 Concept of Container for Toxic Waste



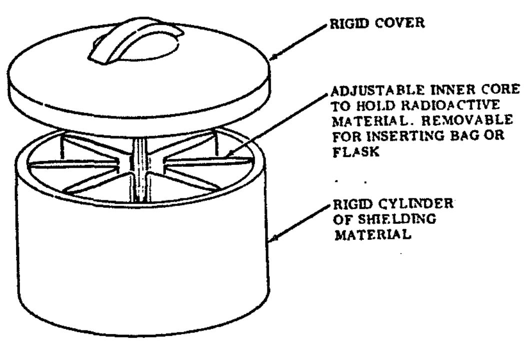


Figure 3.4-6 Concept of Outer Containers for Thermal and Radiation Protection of Inner Containers

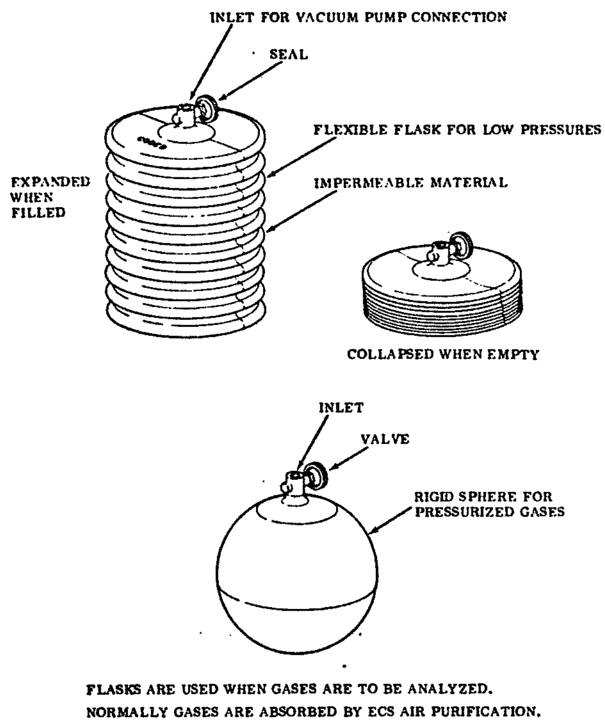


Figure 3.4-7 Concepts of Flasks for Gas Collection

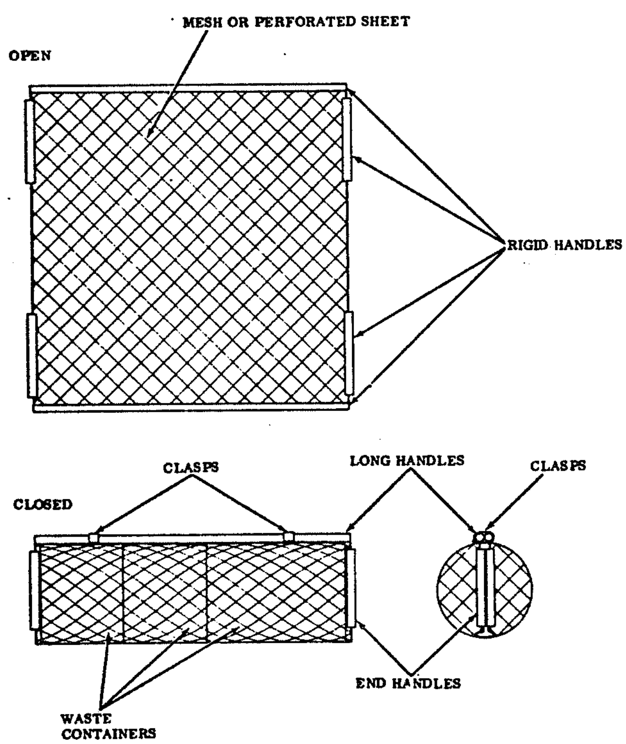


Figure 3.4-8 Concept of Carryall for Waste Containers

TABLE 3.4-8 CONTAINER DATA FOR MANUAL TRANSFER

Candidate Containers	Container Limitations		
	Length Ft.	Diameter Inches	Gross Weight Loaded-lbs.
Flexible Bag	3.0	18	35
Sealable Bag	3.0	18	35
Flask	1.5	12	35
Insulated Outer Container	3.0	18 ID	35
Shielded Outer Container	1.0	12	35

The operational criteria adopted are:

- Zero or partial gravity capability or adaptability
- Pressurized and unpressurized capability
- Basic shirtsleeve IVA operability
- Redundant or backup EVA operability
- Minimum weight, volume, power, and crew requirements

A block diagram identifying the transfer functions for waste handling and housekeeping tasks is presented in Figure 3.4-9, Block Diagram - Transfer Functions.

Figures 3.4-10 through 3.4-18 depict several examples of waste transfer systems presented in Data Book, Volume I. An applicability matrix, defining the application of various transfer systems, is presented in Figure 3.4-19

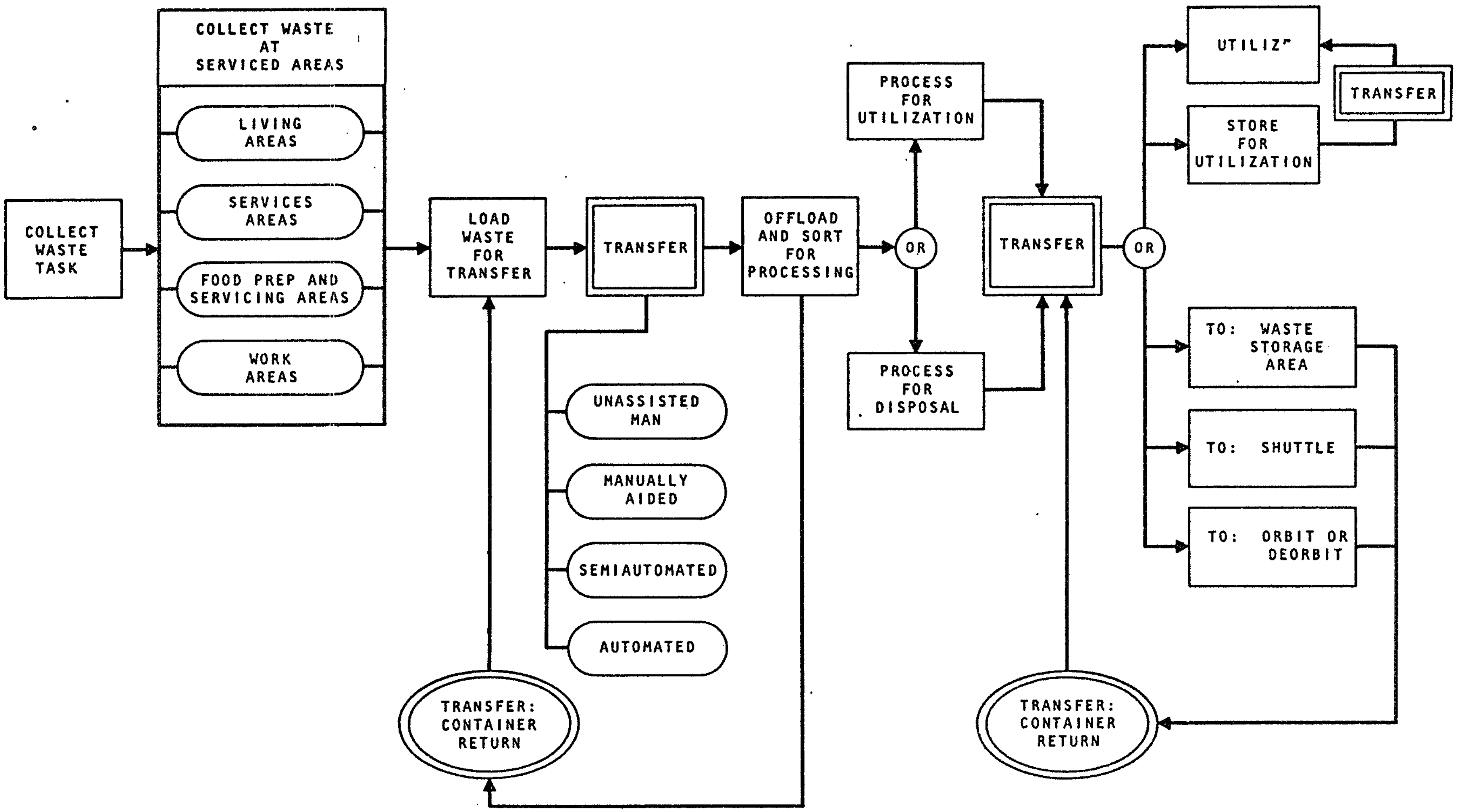
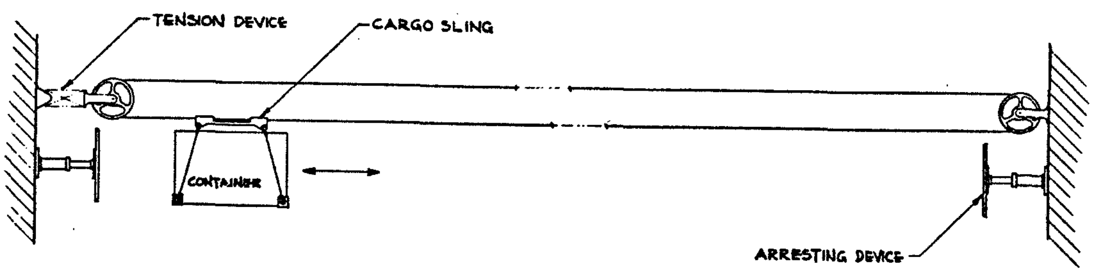


Figure 3.4-9 Block Diagram - Transfer Functions

	- TRANSFER DEVICE - CLOTHESLINE	Concept No. 1



This system is comprised of a continuous cable, rove around two sheaves, to which cargo or waste containers are affixed for manual transfer. Each sheave is firmly mounted to fixed structure, and tautness in the system is maintained by a turnbuckle or other tension device attached to one of the sheaves. Deceleration of the moving load is accomplished by a snubbing device mounted to fixed structure at either end of the line.

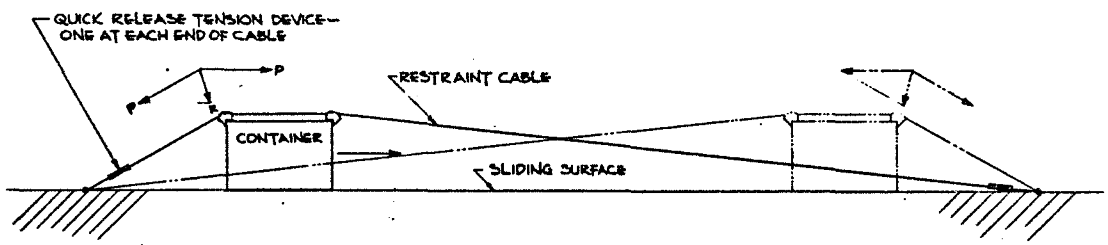
Among the obvious advantages of this scheme are, a) its extreme simplicity, b) it can easily be adapted to a variety of installation situations, and c) it is equally applicable to gravity or weightless conditions.

A disadvantage is its susceptibility to sidewise accelerations.

It is applicable for transportation from work station - to - work station, module - to - module, deck - to - deck, space station - to - shuttle, and other uses.

Figure 3.4-10 Transfer Device - Clothesline

	- TRANSFER DEVICE - BOWSTRING	Concept No. 2



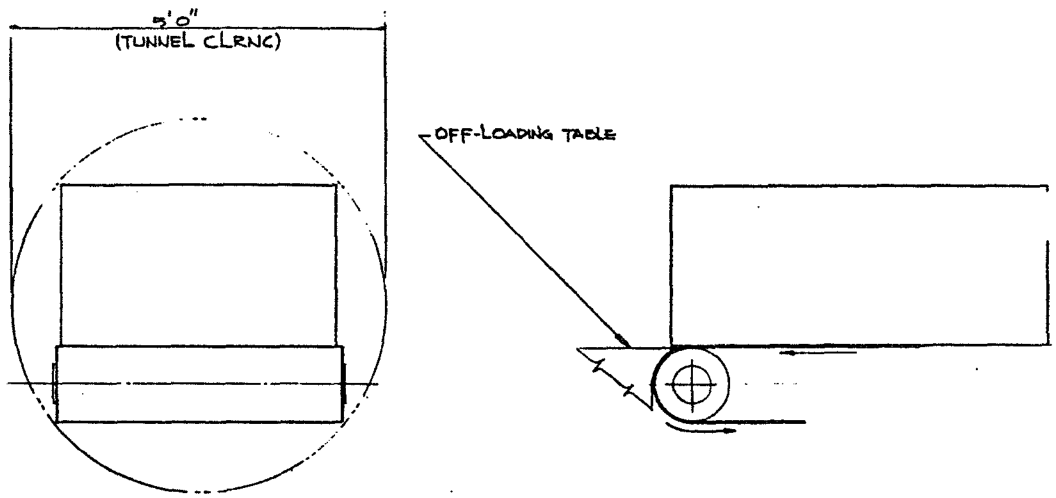
In this system the container is manually slid from place to place. Restraint is provided by a "bowstring" cable, passed over the box and held under sufficient tension so that its downward force component will prevent the container from leaving the surface on which it is sliding.

A salient advantage of this scheme is that there is an inherent decelerating force at the end of the line as shown in the vector diagram in the above sketch. There is a disadvantage in its succeptibility to side forces, which could, however, be met by providing side rails between which the package would move in those situations where side restraint proves necessary.

This scheme would be applicable on the inside walls of intermodular tunnels, or on any flat surface.

Figure 3.4-11 Transfer Device - Bowstring

	- TRANSFER DEVICE - CONVEYOR BELT	Concept No. 3



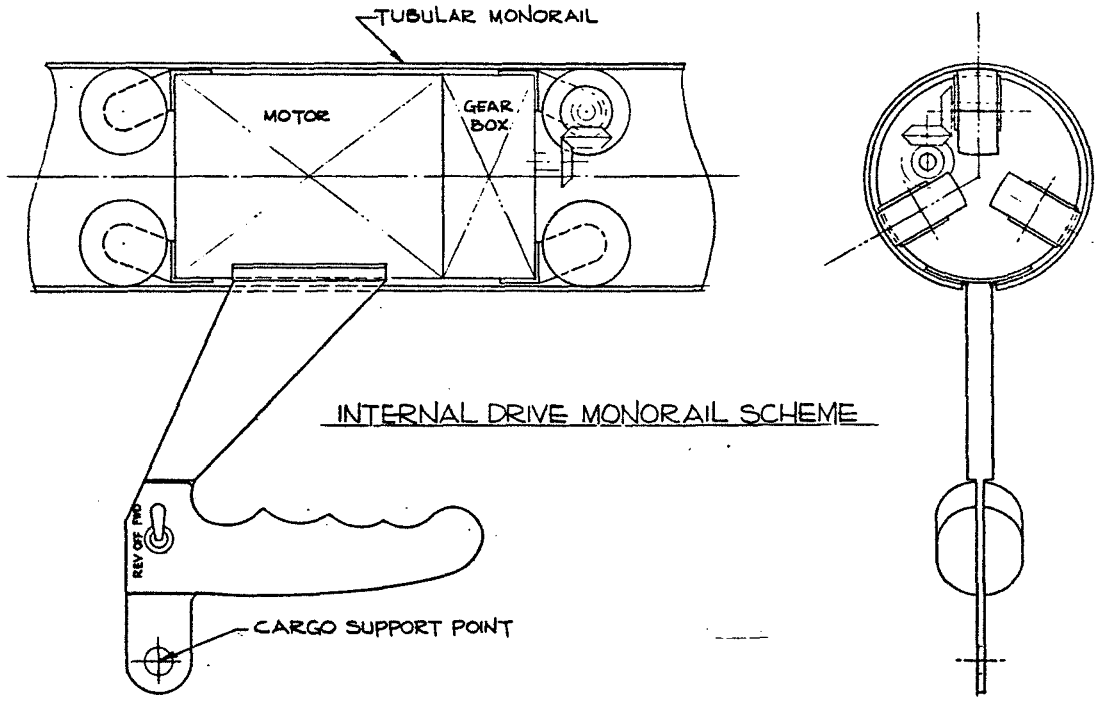
TO SECURE CONTAINER TO BELT:
a) SURFACE BELT WITH VELCRO; BOND STRIPS OF VELCRO TO UNDERSIDE OF CONTAINER.
b) MAKE BELT FROM STEEL MESH; IMBED MAGNETS IN UNDERSIDE OF CONTAINER.
c) EMPLOY ELECTROADHESIVE (ELECTROSTATIC) FORCE.

The conveyor belt is one of the more obvious solutions to the problems of material transfer inherent in space activities. Its operation is straightforward except for difficulties presented by the zero g condition, which requires that the material being moved be prevented from leaving the belt surface by some adhesive force. The required adhesion could be provided by, a) a Velcro belt in conjunction with Velcro strips on the container, b) a steel mesh belt acted on by permanent magnets inbedded in the container, and c) a belt made from a metallic fabric acted by electroadhesive devices incorporated in the container.

This system would find application within the space-station's tunnels, between areas on one deck, and between space-station and shuttle during resupply or waste removal operations.

Figure 3.4-12 Transfer Device - Conveyor Belt

	- TRANSFER DEVICE - RAIL AND TROLLEY Internal Rail	Concept No. 6b



In this system a small diameter tube serves as the monorail. The tube is split on its underside for its entire length to permit egress of a personnel handgrip and cargo hook which is attached to a trolley riding on the inside of the tube. The trolley is composed of a motor-gearbox combination with three equally-spaced wheels mounted on each end. Driving force is provided by one of the wheels located opposite the slit in the tube.

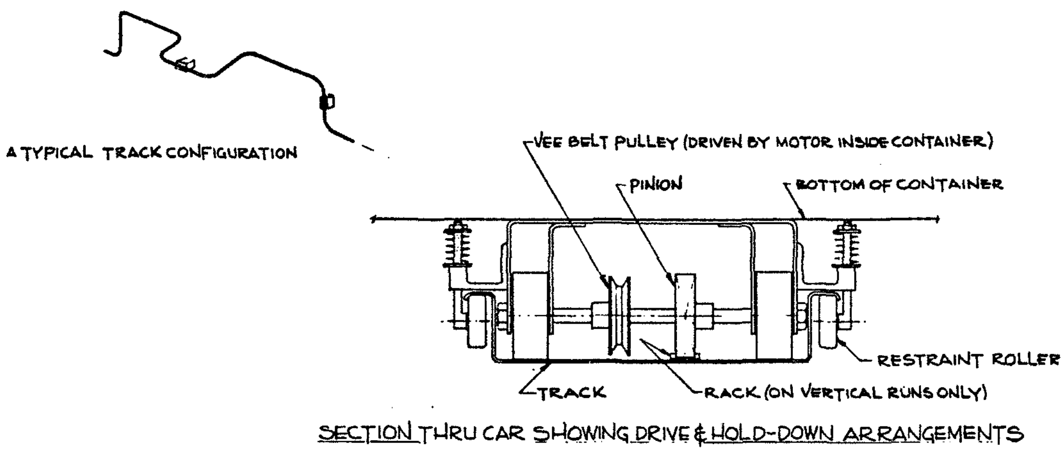
In order to achieve a traverse velocity of three feet per second, reduction ratio in the gearbox and bevel gear final drive is such as to provide rotation of the driving wheel at 612 rpm, for a 3-inch diameter tube system.

Traverse control is by means of a 3-position switch, through which driving, coasting, or braking can be achieved.

While this system is intended primarily for the automated transfer of personnel and/or cargo, it can also be used as an unpowered vehicle where the astronaut launches himself from place to place. This type of usage can be considered as "guided soaring" which obviates power requirements while performing the required tasks of crew and cargo/waste transfer.

Figure 3.4-13 Transfer Device - Rail and Trolley - Internal Rail

	- TRANSFER DEVICE - RAIL AND TROLLEY Automated Car System	Concept No. 6c



This concept proposes a self propelled 4-wheeled cargo-waste car which travels on an inverted hat-section track. Incorporated in the track system are automated turn-table switching units which can switch cars from track to track.

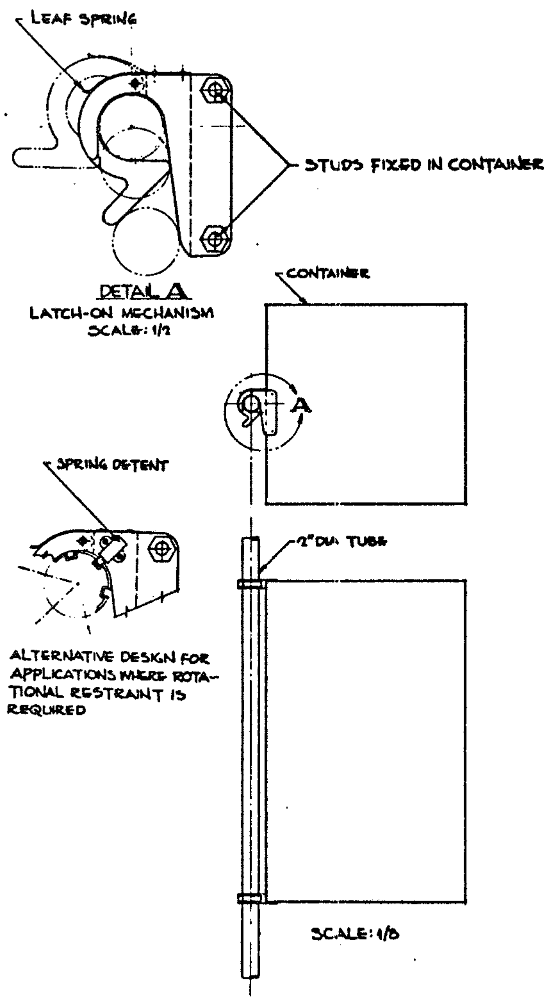
The car is held down (providing a gravitational effect) to the track by spring-loaded restraint rollers, two of which are located on each side of the undercarriage. Drive for level runs is accomplished through friction between the driven pair of wheels and the track surface. For uphill runs, the drive is by a rack-and-pinion arrangement incorporated in the track and the undercarriage.

Routing of cars can be programmed electronically. The operator positions magnetic indicators on the lid to the code number of the receiving station. Switching units read the position of the magnetic indicators as the car passes and direct it to its destination. The Mosler Airmatic Systems Division has developed a system of this nature which lends itself ideally to the problems of transfer in a space station.

This scheme is equally applicable in the presence or absence of gravity forces. Its technical complexity is more than compensated for by the universality of its applicability and by the fact that it is a developed system which can be modified to achieve the space use objectives.

Figure 3.4-14 Transfer Device - Rail and Trolley

	- TRANSFER DEVICE - FIREMAN'S POLE Manual Assist	Concept No. 7a



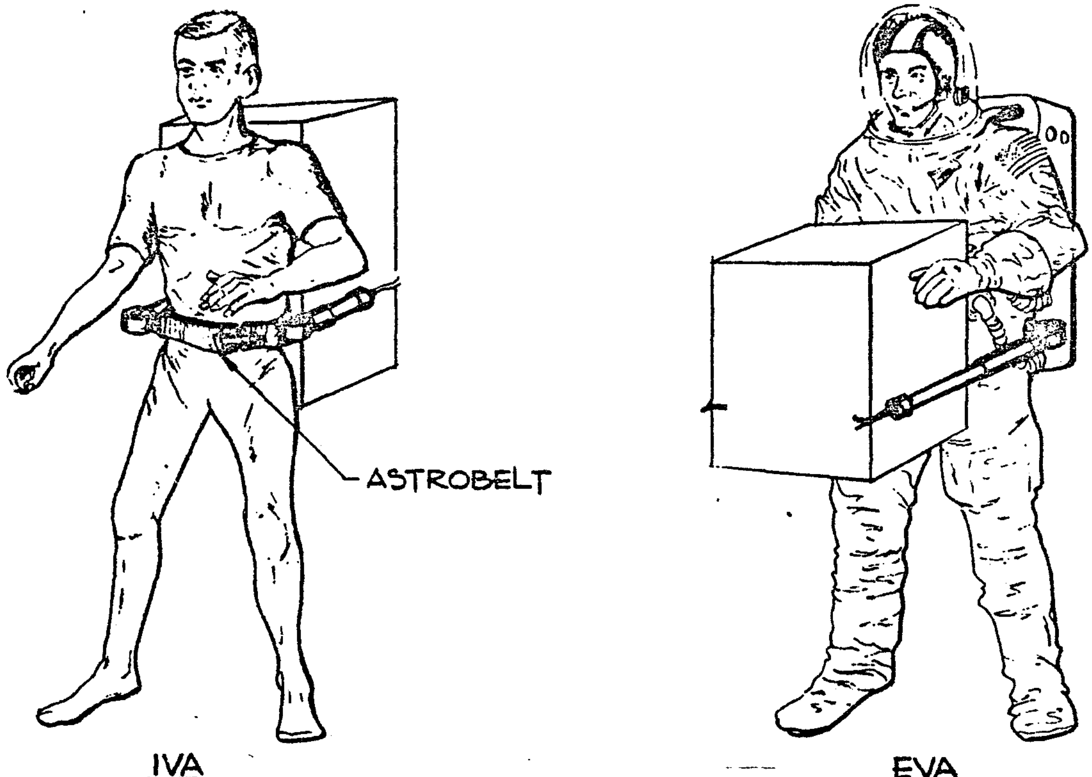
This system envisions a rigid pole which is permanently installed in work areas where repetitive cargo/waste transfer operations take place. Transferred materials are affixed to this pole with a sliding fit through the use of an automatic latch-on mechanism, similar in operating principle to an automatic railroad car coupler, attached to each end of the container. Movement is achieved through manual assist. Deceleration of the load would be achieved by gradually tapering the tube to a larger diameter at the ends.

This concept offers the advantages of intrinsic simplicity, light weight, and low maintenance requirements. Its disadvantage lies in its limited applicability in the presence of gravity forces.

While this scheme is envisioned as being primarily applicable within the tunnels from deck-to-deck, it could be adapted for use with comparable effectiveness in a parallel-to-deck situation.

Figure 3.4-15 Transfer Device - Fireman's Pole

	- TRANSFER DEVICE - BELT SUPPORT	Concept No. 9



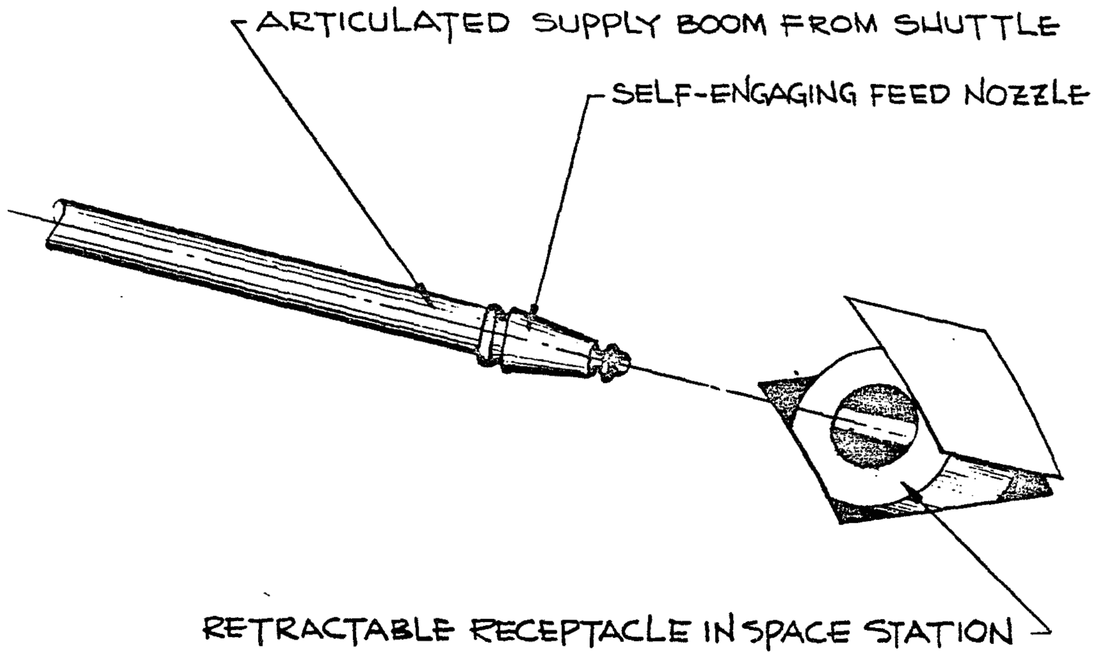
This concept envisages the use of the FH/RAD Astronaut Restraint Unit (Astrobelt) as an aid in waste/cargo handling in intra- or extra-vehicular activity. The ARU consists of a belt assembly which is worn by the astronaut over the Constant Wear Garment (for IVA) and is adaptable to the EVA space suit by providing dual snaplock thru-fittings on each side of the suit for belt and boom attachment. Attached to this belt is a laterally opposed pair of telescoping booms which can be locked to any length within their extension capability, and which are capable of a conical motion envelope thru 250° of rotation in the horizontal plane. Each of these booms can be fitted at its outer extremity with a variety of grippers which can be used to retain cargo-waste containers in any attitude suited to the nature of the task at hand.

With the container supported in this manner, the astronaut's hands are left free to assist him in moving from place to place by grasping handrails or other fixed objects.

The salient advantage of this system is its extreme flexibility of application as to size and shape of container or locus of operation.

Figure 3.4-16 Transfer Device - Belt Support

	- TRANSFER DEVICE - HYDRAULIC FLUID TRANSFER	Concept No. 11

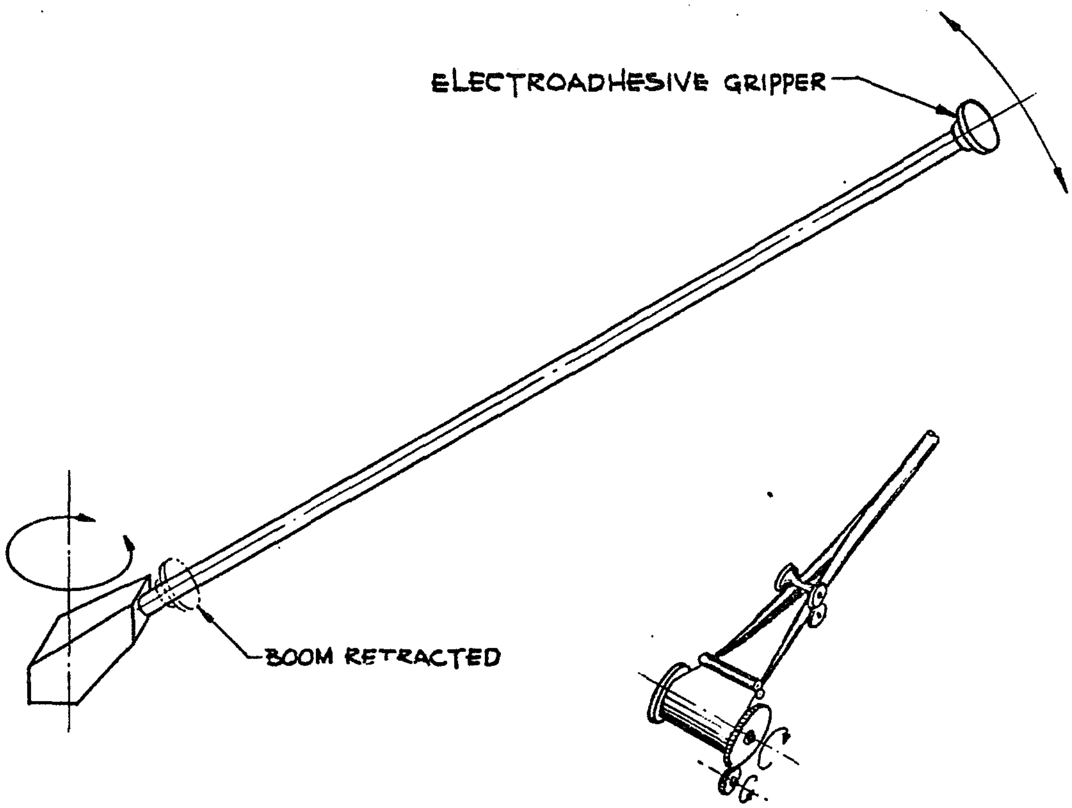


This concept adapts an aircraft-type Boom/Receptacle Refueling system (such as FH/RAD's Inflight Buddy Refueling system) to the transfer of the various fluid materials necessary for life support and functional operation of an orbiting space laboratory.

In an example of this application the shuttle is maneuvered into a position approaching the space station, then under control of a shuttle crew member the supply boom is articulated so that it enters the conical opening in the receptacle which has been deployed clear of the surface of the space station. On full engagement the nozzle automatically locks in place, and fluid transfer takes place.

Figure 3.4-17 Transfer Device - Hydraulic/Fluid Transfer

	- TRANSFER DEVICE - EXTENDIBLE ELEMENT	Concept No. 15



The Tubular Extendible Element (TEE), as developed by Fairchild Hiller, is an extendible tubular boom, which on retraction, is reformed into a pre-stressed flat sheet that can be rolled up on a drum for stowage. Pre-stress parameters in the sheet are maintained at such levels as to ensure that the strip will always reform itself into the same size tube when the device is extended.

This concept proposes to attach a gripping chuck, such as an electroadhesive or mechanical device, to the end of the TEE for use in the transfer or waste/cargo in either the IVA or EVA mode (e.g., deck-to-deck, module-to-module, station-to-shuttle).

This use of the TEE offers the advantage of extreme flexibility of adaptation because of its small size and its portability. Its disadvantage is to be found in the fact that sufficient rigidity for use in anything but a weightless environment might prove difficult of achievement.

Figure 3.4-18 Transfer Device - Extendible Element

WASTE/CARGO AUTOMATED TRANSFER DEVICES APPLICABILITY MATRIX

	TRANSFER SYSTEM		INTRA-STATION TRANSFER: BETWEEN DECK/COMPARTMENT	INTRA-STATION TRANSFER: DECK-TO-DECK PASSAGEWAY	INTRA-STATION TRANSFER: DECK-TO-DECK AIRLOCK	INTER-STATION TRANSFER: ATTACHED MODULES - OPEN	INTER-STATION TRANSFER: ATTACHED MODULES - AIRLOCK	SHUTTLE OR CARGO MOD-TO-STA TRANSFER: DOCKED SHUTTLE-TO-STA	SHUTTLE OR CARGO MOD-TO-STA TRANSFER: DOCKED MODULE-TO-STA	SHUTTLE OR CARGO MOD-TO-STA TRANSFER: FREE-FLYING ELEMENT-TO NEARBY STATION OR SHUTTLE	TRANSFER BETWEEN UNATTACHED ORBITAL ELEMENTS: STATION-TO-STATION	TRANSFER FROM STA-TO-EARTH, MOON, SUN: INTACT TRANSFER	TRANSFER FROM STA-TO-EARTH, MOON, SUN: DISINTEGRATION OR DESTRUCTION TRANSFER
1	CLOTHESLINE		*	*	*	*	*	*	*	*			
2	BOWSTRING		*	*	*	*	*	*	*				
3	CONVEYOR BELT		*	*	*	*	*	*	*				
4	ROLLER CONVEYOR		*	*		*		*	*				
5	DUMBWAITER			*		*		*					
6a	WALL/CEILING MOUNTED RAIL AND TROLLEY	EXTERNAL RAIL	*	*	*	*		*					
6b		INTERNAL RAIL	*	*	*	*	*	*	*	*			
6c		AUTOMATED CAR TRANSFER SYS	*	*	*	*		*					
7a	FIREMAN'S POLE	MANUAL ASSIST		*	*	*	*	*	*				
7b		AUTOMATED		*	*	*	*	*	*	*			
8a	TRICYCLE ELEVATOR	ZERO-G TYPE		*		*							
8b		PARTIAL OR FULL-G TYPE		*		*							
9	BELT SUPPORT (FH/RAD ASTROBELT)		*	*	*	*	*	*	*	*			
10	RIGID ARM LINKAGE			*	*	*	*	*	*	*			
11	HYDRAULIC/FLUID TRANSFER									*			
12a	PNEUMATIC TRANSFER	TUBE OR SHAFT TYPE	*	*	*	*	*	*	*				*
12b		VACUUM CLEANER	*	*	*	*	*	*	*				
13	LAUNDRY CHUTE			*	*	*	*	*	*				
14a	MANEUVERING/PROPULSION UNIT	EXPENDABLE TYPE									*		*
14b		RECHARGEABLE/REFURNISHABLE								*	*	*	
15	EXTENDABLE ELEMENT (FH TEE DEVICE)			*	*	*	*	*	*	*			
16	GRAPPLING HOOK		*	*	*	*	*	*	*				

Figure 3.4-19 Applicability Matrix - Transfer Systems

3.5 WASTE CONTROL SEARCH/REPORT COMPUTER PROGRAM

3.5.1 Introduction

This study resulted in the accumulation of a large body of data on the sources and quantities of waste material to be generated on future large spacecraft, the equipment and manpower requirements for on-board handling and storage of this material, and the hardware processes that can be used to recover and/or prepare for disposal (removal from the spacecraft) of particular classes of wastes. The body of data so far gathered is already large and can be expected to expand as development of the large system concepts proceed. Moreover, the data so far gathered represents, in many cases, preliminary estimates or surmises based on spacecraft systems or features that are in very early planning stages. Accordingly, continual revisions of the data, including correction, addition of new items, and deletion of others, will be required to keep the material current.

Future use of the data will require, among other things, search and retrieval of specific data items and sorting or collection of specific groups of data; for example, it will be desired to itemize all the waste materials and their quantities originating in a given spacecraft area or to list all waste items having some specified attributes. These sorting processes correspond to the actual waste handling and housekeeping procedures that will occur on real systems.

3.5.2 Program Description

Development of a computer program to accomplish the aforementioned requirements was accordingly accomplished. Specifically, the following objectives were sought:

- Development of means of storing and providing fast access to data banks of information on the waste handling aspects of spacecraft housekeeping.
- Provision of means for keeping the data current--updating-- by revision and inclusion of new data
- Provision of data book report format printout of the contents of the data bank in order to facilitate data book revision
- Development of search and sort retrieval capability on the file data

Figure 3.5-1 shows schematically the relationships between the various sections of the program. Provision has been made for four separate collections of data:

- Waste material source and property data

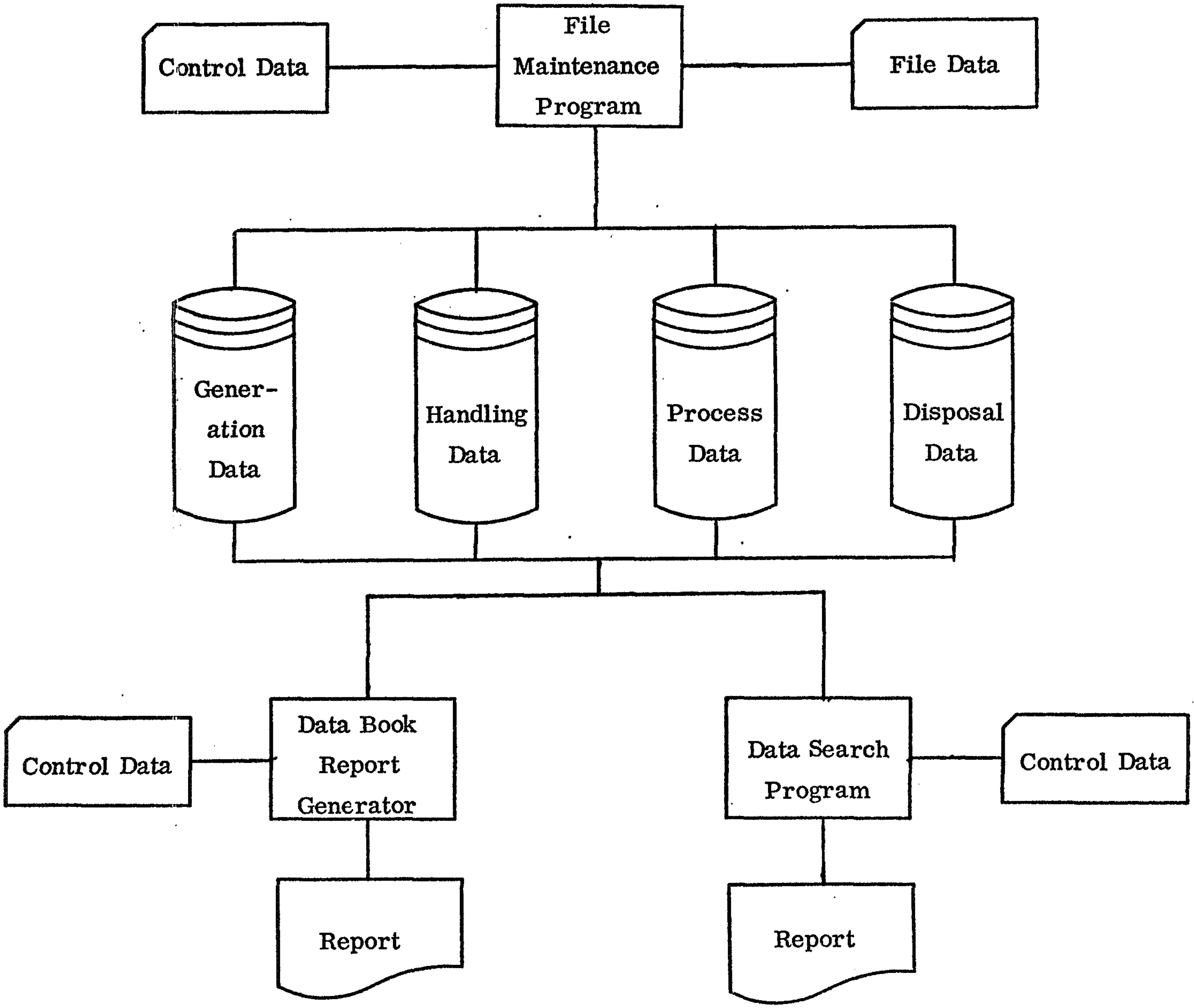


Figure 3.5-1. Housekeeping Waste Control Program - Schematic

- Waste handling and housekeeping data
- Waste treatment and utilization process data
- Disposal methods and systems data

Three separate sections of the basic program provide access to the data to perform the various functions described in the following subsections.

3.5.2.1 Data Structure

The data generated during the present study contains large amounts of textual material in addition to numerical data. Program development was oriented towards incorporating both types of data in the data files and in permitting a reasonable amount of flexibility in the length of given textual data items. The organization of the data is such as to permit fast access for the purposes of:

- Updating
- Search of textual material for keywords or phrases, such as specified waste attributes
- Summation of numerical quantities, such as quantity of waste material produced within specified spacecraft area

The specified data items contained in each data file are detailed in the following sections; the program structure is such that addition of new types of data in the future could be easily accomplished by minor program modification together with an update operation on the data files. In general, it has been the objective to establish a program structure sufficiently general that such additions can be easily accomplished as the spacecraft housekeeping problems become more clearly defined. Moreover, many data items cannot, at the present time, be filled in, due to lack of definition at this stage of mission planning, etc.

3.5.2.1.1 Waste Material Generation File

The waste material generation file has been organized so as to include as much as possible of the waste definition data generated during this study, as contained in Volume II of the Data Book. The data has been collected into groups each containing all data relating to a specific spacecraft laboratory or subsystem; all spacecraft waste data is thereby included.

The data is further subdivided successively according to experiment or equipment, waste source, and waste item. Table 3.5-1 shows the specific categories of data and their structural relationship. Detailed description of the nature of the data and its source can be obtained by reference to Volume II.

3.5.2.1.2 Waste Material Handling File

Table 3.5-2 shows the structure of the data elements as presently provided by the file maintenance program. The data is divided into five basic groups corresponding to housekeeping procedures and equipment. The principal data items included at present are the waste attributes associated with each procedure or equipment, permitting selection by the search program of suitable procedures and equipment for handling various types of waste, equipment associated with each procedure (for cross-reference purposes), and manpower requirements.

3.5.2.1.3 Waste Material Utilization and Treatment Process File

Table 3.5-3 depicts the data structure that has been implemented in the program. As mission planning and systems development for large long-duration manned spacecraft proceeds, this data for specific processes can be placed in file and accessed by the search program.

3.5.2.1.4 Waste Disposal Data File

Table 3.5-4 shows the structure of data presently established for waste disposal data. This data is similar in nature to that of the proceeding file.

3.5.2.2 File Maintenance

The file maintenance portion of the program provides the following capabilities:

- ab initio creation of new data files on direct access storage devices (magnetic disk)
- Revision of existing data in any file
- Expansion of detail in any section of data in the files
- Deletion of any section of the data as desired

System utility programs are used to produce backup copies of the data on magnetic disk, to unload the data unto magnetic tape (for convenience in transportation, etc.), to reload the tape unto direct access storage, and to remove deleted records from the file, etc.

TABLE 3.5-1

DATA STRUCTURE, WASTE GENERATION FILE

1. Subsystem/Laboratory
   2. Name
   2. Function/Requirement
   2. Spacecraft Function
   2. Experiment/Equipment
      3. Name
      3. Area Name
      3. Associated FPE
      3. Waste Source
         4. Name
         4. Document Reference
         4. References
         4. Remarks
         4. Waste Item
            5. Name
            5. Quantity
            5. State
            5. Attributes
            5. Composition
            5. Density (Average)
            5. Reclamation Requirement

TABLE 3.5-2

DATA STRUCTURE, HANDLING FILE

1. Collection and Pickup Procedure
   2. Category Identifier
   2. Procedure Name
   2. Waste Attributes
   2. Equipment Required
   2. Manpower
1. Transfer and Storage Procedure
   2. Category Identifier
   2. Procedure Name
   2. Waste Attributes
   2. Equipment Required
   2. Manpower
1. Sorting and Disposition Procedure
   2. Category Identifier
   2. Procedure Name
   2. Waste Attributes
   2. Equipment
   2. Manpower
1. Container
   2. Category Identifier
   2. Name
   2. Waste Attributes
   2. Design Criteria
1. Transfer Aid
   2. Category Identifier
   2. Name
   2. Waste Attributes
   2. Design Criteria

TABLE 3.5-3

DATA STRUCTURE, PROCESS FILE

1. Processing Method
   2. Process Name
   2. Input Material
      3. Waste Names (A)
      3. Attributes (B)
   2. Consumables (C)
   2. Output Materials (D)
   2. Process Variables
      3. Electrical
      3. Thermal
      3. Manpower
   2. Process Function (E)
   2. References (F)

TABLE 3.5-4

DATA STRUCTURE, DISPOSAL FILE

1. Disposal Method
   2. Method Name
   2. Waste Attributes (A)
   2. Processes Required (B)
   2. Consumables (C)
   2. Process Variables
      3. Electrical
      3. Thermal
      3. Manpower
   2. Design Constraints (D)
   2. References (E)

Card input control information for processing a set of data specifies the file name, nature of operation desired (creation of new file, updata of existing record or addition of new record), and a key identifier for each block of data. Location of data within the file is done by use of this key. The data is also input in card form (or card image); spacial coding sheets have been prepared to facilitate this operation. Any individual data element within a group can be revised in an update operation.

3.5.2.3 Data Book Report Program

The second section of the program prepares a printout of the entire contents of the data files in a format suitable for inclusion in Volume III, "Search/Report Computer Program Data Output." Figure 3.5-2 shows a sample page format of the printout of the waste generation file. At the present stage, the program does not include any formats for the handling, process, or disposal files; these formats will be developed during the later phases of system development when the nature of the data in these files becomes better determined.

3.5.2.4 Data Search Program

The purpose of this third section of the waste material data program is to permit retrieval of lists of data elements satisfying specified criteria from the information contained in the data files. Any number of searches can be performed on a given computer run. For a particular search, the files desired, the specific data elements, and the quantities or values sought are input in card form. Search is accomplished by reading in succession each record of the desired files and testing for matches between the contained data and the desired values (search keys). When a hit is made, the data is printed on a search report.

The purpose of the report format at the present stage of program development is to provide sufficient data for each hit that a definitive reference to the data book file printout is provided; through this reference, any other desired information about the located items can be obtained manually. This reference is provided by giving the major indentation identifiers of the data structures, for example, in the waste generation file, the S/C subsystem, equipment/experiment name, the waste source name, and the waste item name, together with the operational description document number.

The program logic is arranged to permit a search with any number of search keys for a specified search of the file, using either AND or OR logic, i.e., recording lists only when all keys are satisfied, or when any key is satisfied, respectively. This option affords considerable flexibility in grouping the data for analysis purposes.

```
10/22/70                        RUN NO. ** I **

S/C SUBSYSTEM ..... PROVIDE PERSONAL ARTICLES
    GROUP KEY ..... 1.2.2
*******************************************************************

          BASIC FUNCTION ............ SUPPORT LIFE
          FUNCTIONAL REQUIREMENT .... PROVIDE CREW QUARTERS


** EQUIPMENT/EXPERIMENT NO.  1 ...... CLOTHING

          ASSOCIATED FPE NUMBER ...
          S/C AREAS ......... BED ROOM


**** WASTE SOURCE NO.  1 .... CLOTHING

          DOCUMENT NO. ...... 1.2.2.1.1*

          REFERENCE NO.  1 .. PRELIMINARY DEFINITION-INTERGRATED HYGIE
                              NE SYSTEM MATERIAL PROVISIONS, FHR #3871
                                JANUARY 29,1970 FH/RAD


****** WASTE ITEM NO.  1 .... SOILED SHIRT SHORT SLEEVE
          STATE ............. SOLID
          DENSITY ...........  17.00 LBS/CU. FT.
          ATTRIBUTES ........ TEXTILE SHEET
          ELEMENTS PRESENT .. H, C, O,
          COMPOSITION ....... CELLULOSE
          GENERATION DATA ...
                   NO. OF MEN             RATE(LBS/YEAR)
                     12                      428.00
                     50                     1782.00
                    100                     3564.00
          RECLAMATION ACTION .. LAUNDER

****** WASTE ITEM NO.  2 .... SOILED TROUSERS
          STATE ............. SOLID
          DENSITY ...........  17.00 LBS/CU. FT.
          ATTRIBUTES ........ TEXTILE SHEET
          ELEMENTS PRESENT ..
          COMPOSITION ....... CELLULOSE
          GENERATION DATA ...
                   NO. OF MEN             RATE(LBS/YEAR)
                     12                      609.00
                     50                     2541.00
                    100                     5082.00
          RECLAMATION ACTION .. LAUNDER

            ** MANNED SPACECRAFT WASTE GENERATION DATA **
```

Figure 3.5-2. Sample Waste Generation Data Printout

```
10/22/70                      RUN NO. ** 1 **

S/C SUBSYSTEM ..... PROVIDE PERSONAL ARTICLES
    GROUP KEY ..... 1.2.2
** EQUIPMENT/EXPERIMENT NO.  1 .......CLOTHING

**** WASTE SOURCE NO.  1 .... CLOTHING

********************************************************************

****** WASTE ITEM NO.  3 .... SOILED JACKET, LIGHT WEIGHT
         STATE ............ SOLID
         DENSITY ..........  19.00 LBS/CU. FT.
         ATTRIBUTES ........ TEXTILE SHEET
         ELEMENTS PRESENT ..
         COMPOSITION ....... CELLULOSE
         GENERATION DATA ...
                  NO. OF MEN              RATE(LBS/YEAR)
                     12                         8.00
                     50                        34.00
                    100                        68.00
        RECLAMATION ACTION .. LAUNDER

****** WASTE ITEM NO.  4 .... SOILED UNDERSHORTS
         STATE ............ SOLID
         DENSITY ..........  18.00 LBS/CU. FT.
         ATTRIBUTES ........ TEXTILE SHEET
         ELEMENTS PRESENT ..
         COMPOSITION ....... CELLULOSE
         GENERATION DATA ...
                  NO. OF MEN              RATE(LBS/YEAR)
                     12                       440.00
                     50                      1836.00
                    100                      3672.00
        RECLAMATION ACTION .. LAUNDER

****** WASTE ITEM NO.  5 .... SOILED UNDERSHIRTS
         STATE ............ SOLID
         DENSITY ..........  18.00 LBS/CU. FT.
         ATTRIBUTES ........ TEXTILE SHEET
         ELEMENTS PRESENT ..
         COMPOSITION ....... CELLULOSE
         GENERATION DATA ...
                  NO. OF MEN              RATE(LBS/YEAR)
                     12                       440.00
                     50                      1836.00
                    100                      3672.00
        RECLAMATION ACTION .. LAUNDER


        ** MANNED SPACECRAFT WASTE GENERATION DATA **
```

Figure 3.5-2. Sample Waste Generation Data Printout (Cont'd.)

4.0 RECOMMENDATIONS FOR FUTURE WORK

It is recommended that the housekeeping data available from this program be updated, expanded, and applied to specific mission models. It is also recommended that related efforts be performed and that hardware development be initiated to demonstrate feasibility for candidate housekeeping concepts so that the technology will be available when firm system requirements are established and full-scale manned space system development is initiated.

4.1 Data Updating, Expansion, and Application

4.1.1 Update Waste Definition

Updating of the data book is necessary to include the current applicable data available as a result of the Skylab program, space station, space base and shuttle definition programs, module conceptual study programs, experiment candidate definition and experiment grouping studies, habitability studies, and other related studies and programs. In addition, NASA should consider exploiting the study and development programs presently underway or planned, which are excellent sources of data on wastes and consumables/expendables. The exploitation of the data buried in those programs can be facilitated by the generation and contractual application of a NASA Data Requirements Description form in a format similar to the waste definition data packages used in Volume II of the Data Book. By standardizing the input format, the waste characteristics and the terminology, any system investigator can supply a more expert and a more current operational description, consumables/expendables list and waste list for the individual waste sources that are being studied.

The collection of this data, the updating of the data book, and the dissemination of the updated data to potential users would be performed by a data integrator.

4.1.2 Expand the Data Bank for the Decision-Making Process

The waste definition data should be correlated to the penalties associated with the collection, handling, sorting, utilization and/or disposal of wastes in order to allow the optimization of crew time, equipments, and procedures for waste control. The following additional sequence of tasks should be performed:

a) Improve and expand the correlation between the waste item characteristics and the characteristics of the equipments, routines, and personnel.

b) Apply the material characteristics to all waste items, equipments, and procedures in the Data Book (Volumes I and II)

c) Update computer data bank information - Volume III of Data Book to include the preceding information.

d) Establish a set of general housekeeping requirements keyed to the standardized material characteristics.

e) Establish trade study models for housekeeping/resupply decisions.

f) Expand computer program from its present search capability to include the capability of totalizing and/or computing by key-word material characteristics so as to be compatible with any selected trade study models.

4.1.3 Application of Data to Specific Missions

Application of the waste definition and waste control data to specific space missions is required to arrive at real housekeeping solutions. The results of this effort should include an initial set of mission housekeeping requirements followed by concept selections and preliminary designs of waste control items for specific models of space stations, space shuttle, and mission modules.

The application of this data to specific missions should include the following tasks:

a) Using updated criteria for the specific mission and time period, exercise the available utilize/dispose trade study models. Establish break-even rates for economical on-board processing for utilization. Make on-board processing for utilization decisions for materials with specific characteristics.

b) Using previously established general housekeeping requirements and the specific wastes associated with a specific mission, generate specific mission housekeeping requirements. Perform the necessary trade studies or optimization studies to define properly the requirements for the mission waste module and associated waste collection, handling, pretreatment, sorting, transfer, and equipments required.

c) Based on the preceding requirements, perform concept selections and preliminary designs on systems for waste control and interfacing with waste utilization.

d) Using mock-ups of the mission waste module(s) and other spacecraft areas and housekeeping equipments, perform manned simulations of the particular mission housekeeping problems. Verify human factor requirements definition, optimize crew-time procedures, and verify the hardware and waste module suitability.

4.2 Related Efforts

4.2.1 International Agreement - Space Pollution

International agreement is required on both the allowable materials to be jettisoned and the method of jettisoning these materials from a spacecraft. The recommendation here is to establish a formalized NASA - other nation committee to analyze the problem and determine appropriate agreements on the control of waste jettisoning in space. Cooperation with the UN and the International Institute of Space Law in the International Astronautical Federation, Paris, is indicated.

4.2.2 Coriolis Studies

It is recommended that a study be performed of space base rotation rates, acceleration vectors, and gravity gradients combined with analysis of astronaut motion sequences, locomotion paths, techniques, and work cycles to produce optimum work and housekeeping practices designed to minimize coriolis effects.

4.2.3 Material Handling Techniques

A program of research in cargo handling techniques in simulated zero and partial gravity is recommended. Neutral buoyancy underwater procedures; sling, centrifuge and air bearing simulations; and Keplerian trajectory flights will provide some insight.

4.2.4 Logistics Planning

An adaption of the consumables/expendables data and the waste data to computer programming techniques for logistics planning purposes is recommended.

4.2.5 Non-Space Applications

The data collection, preparation, and processing techniques developed for manned spacecraft waste control decision making should be applied to different segments of the terrestrial waste control problem.

4.3 Hardware Development

The materials produced as waste products must be collected, pretreated in some cases, transferred and then either utilized or disposed of. It is recommended that a family of hardware concepts be developed for each of these functions as a shopping list for the future system planner. The following sections identify the hardware concepts recommended for further development. Characteristics of the material to be handled as well as other pertinent design considerations are also indicated.

4.3.1 Collect and Contain Wastes

The waste can be manually collected and placed in a storage and transfer container or, alternately, the waste can be air collected in an automatic or semiautomatic manner and deposited in a bag or other container. Table 4-1 lists the hardware items considered for development.

4.3.2 Hardware To Pretreat Wastes

Certain classes of waste materials have characteristics that constrain the handling, disposal or utilization of these wastes. To obviate these constraints, pretreatment of the wastes for disposal or utilization or for simply handling is advised. Table 4-2 lists the hardware items considered for development; principal usage and comments are also supplied.

4.3.3 Material Transfer

The waste material once collected must be transferred from the area of origin to the area where it will be pretreated, utilized, or disposed of. Material handling techniques and equipments will be required to reduce crew time. Some of the techniques and equipments used in cargo handling and transfer can be applicable. Figure 3.4-19 includes a list of candidate waste/cargo transfer devices and the governing design conditions that are satisfied by the concept.

4.3.4 High Rate Expendables Processing

Expendables that are consumed at a high rate (i.e., greater than 50 to 100 lbs/month) warrant examination to determine if an onboard salvage or reclamation process can be developed to reduce the resupply requirements. Such developments would reduce the impact of the expendables on waste control. The high rate expendables anticipated and the necessary processing hardware are shown in Table 4-3.

4.3.5 High Rate Consumables Manufacturing

Material consumed at a high rate (i.e., greater than 50 to 100 lbs/month) warrant study to determine if they can be manufactured on-board from the waste materials available. Materials so replaced would reduce the resupply requirements and reduce the waste control load by the amount of waste material utilized. The high rate consumables anticipated and the necessary manufacturing processes are shown in Table 4-4.

4.3.6 Waste Disposal

Disposal has been defined for the purposes of this study as "removal from the spacecraft." Removal has been further subdivided into classes that satisfy a particular constraint or material characteristic. Table 4-5 lists the hardware items considered for development.

TABLE 4-1. WASTE COLLECTION AND CONTAINMENT

Equipment Type	Hardware Items	Material Characteristics
Manual collection - bags	a) Flexable bag	Solid, liquid, mixture Non toxic/sterile, inert, disposable
	b) Sealable impermeable bag	Solid, liquid, mixture, pathogenic Toxic, noxious, contaiminated disposable
Manual collection - Containers	a) Insulated, rigid container	Solid, hot or cold
	b) Shielded, rigid container	Solid, radioactive
Fluids collection	a) Flask (pressure vessel)	Gaseous, volitile
Combination containers	a) Bag in insulated container	Bag characteristics + hot or cold
	b) Bag in shielded container	Bag characteristics + radioactive
Air collectors	a) Vacuum cleaner	Non-toxic, dry, Air retrainable particles

TABLE 4-2. PRETREATMENT OF WASTE

Pretreatment Method	Hardware Concept	Principal Usage	Comments
Desiccation	Static Food Waste Desiccator	To deactivate waste for predisposal storage	• Requires water recovery or venting of water vapor
Desiccation	Rotary Food Waste Shredder/ Desiccator	To deactivate waste for predisposal storage	• Requires water recovery or venting of water vapor • Deactivates large quantities of waste before requiring emptying • Minimizes waste handling
Desiccation	Rotary Slurry Waste Desiccator	To deactivate waste for predisposal storage	• Requires water recovery or venting of water vapor • Deactivates large quantities of waste before requiring emptying • Minimizes waste handling • Designed to interface with waste plumbing system • Slurry can be piped thru bulkheads
Desiccation	Static Condenser	To recover water from desiccators	• Utilizes surface tension gradients to effect fluid transfer
Desiccation	Rotary Condenser	To recover water from desiccators	• Utilizes centrifugal force to effect fluid transfer.
Refrigeration	Waste Storage Refrigerator	To deactivate waste for predisposal storage	• Refrigeration is the most reliable neans for deactivating waste • Cools waste by evaporation of its moisture content • Requires vacuum source

TABLE 4-2. PRETREATMENT OF WASTE (cont'd)

Pretreatment Method	Hardware Concept	Principal Usage	Comments
Radiation	Gamma Ray Sterilizer for Liquids	• To sterilize liquids for pre-disposal storage • To sterilize a contaminated water supply • To sterilize water emergency from water recovery units	• Low temperature sterilizer • No interface with vehicle power supply
Moist Heat	Autoclave	Routine sterilization of microbiological and hospital waste	• Sterilizes both liquids and solids • Not suitable for materials immiscible in water • Rapid means of sterilization; 15 min @ 250°F
Dry Heat	Dry Heat Sterilizer	Routine sterilization of microbiological and hospital waste	• Sterilizes materials adversely affected by moisture • Not suitable for aqueous materials • Relatively slow means of sterilization; 2 hrs @ 320°F
Gaseous Sterilization	Ethylene Oxide Sterilizer	Routine sterilization of microbiological and hospital waste	• Suitable for heat or moisture sensitive materials • Toxic, corrosive • Relatively slow means of sterilization; 4-8 hours
Compaction	Waste Compactor	To reduce the volume of waste for efficient packaging	• Designed to compact entire waste container to avoid contamination of compactor
Shredding	Dry Waste Shredder	To condition waste for high density compaction	

TABLE 4-3. HIGH RATE EXPENDABLES PROCESSING

Concept Title	Material Treated	Candidate Process
Wash Water Recovery System	Contaminated Wash Water	• Filtration • Distillation • Reverse Osmosis
Dish Washer	Cooking/Eating/Serving Utensils	Emulsification and Dilution
Clothes Washer	Clothes/Bedding/Towels	Emulsification and Dilution
Sorbant Cannister Revitalization Unit	Atmospheric Sorbants, i.e., Odor Control Filters	Thermal/Vacuum Reactivation
Battery Charger	"Dead" Batteries	Reversal of Original Chemical Reaction
Filter/Wicks Cleaner	Clogged Mechanical Filters and Wicks	Reverse Flush Wash Sterilize
Photo Bath Revitalization Unit	Exhausted Photographic Chemicals	Reverse Chemical Reaction
Culture Media Reuse Unit	Used Agar Gel	• Filtration • Sterilization
Equipment Sterilizer	Biological/Medical/Chemical Glassware	Sterilization (Washing)
Reusable Wipes Sanitizer	Used Wipes	Sterilization (Washing)
Repair Bench	Failed Electrical/Mechanical Items	Repair Failed Component or Create Spares From Good Parts

TABLE 4-4. HIGH RATE CONSUMABLES MANUFACTURING

Concept Title	Waste Resource	Consumables Produced	Candidate Process
Nitrogen Recovery Unit	Food (Organic) Wastes, Feces	N_2	Wet Oxidation
Oxygen Recovery Unit	CO_2, Waste Water	O_2	• CO_2 Reduction • Electrolysis
Food Synthesizer	Food (Organic) Wastes	Food	• Chemical Food Synthesis • Plant Food Synthesis • Bacterial Food Synthesis
Water Recovery Unit	Condensate Reclamation Urine Water Wash Water	Potable Water	Distillation/Sorption/ Filtration
Back Pack Recharger	$Li\,CO_3$ From EVA	Li OH	Find Alternative CO_2 Sorbant

TABLE 4-5. DISPOSAL METHODS

Disposal Method	Hardware Concept	Principal Usage	Advantages	Disadvantages
Return to earth via shuttle	Waste Module	Baseline Disposal method	Maintained on earth. Increased station autonomy. Complete disposal method. Eliminates on board processing.	Transfers disposal problem to earth.
Jettison to earth for aerodynamic incineration	Rocket propelled cannister and launch mechanism	Contingency disposal method	Permits disposal to be current, independent of shuttle.	Expendable containers and motors. On board storage of explosives.
Jettison in orbit	Pyrolytic incinerator	Contingency disposal method	Permits disposal to be current, independent of shuttle. Minimizes material handling.	Contributes to external debris atmosphere. Large energy requirement.
Jettison to outer parking orbit	Rocket propelled cannister and launch mechanism	Radioactive waste disposal	Provides option for later recovery.	Expendable containers and motors. On board storage of explosives.
Jettison to solar orbit	Rocket propelled cannister and launch mechanism	Radioactive waste disposal	Complete disposal for hazardous waste (earth pollutant)	Expendable containers and motors. On board storage of explosives.